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Only in God's country could you

While Canada's Pacific coast is still undiscovered by many of this world, our native peoples have been entertaining visitors for centuries.

The Raven beat his wings, in perfect rhythm, until he had formed our world out of nothing at all. And marked the beginning of life as we know it.

The most revered of spirits and master of ceremonies, the Raven embodies what this land is today. Magic.

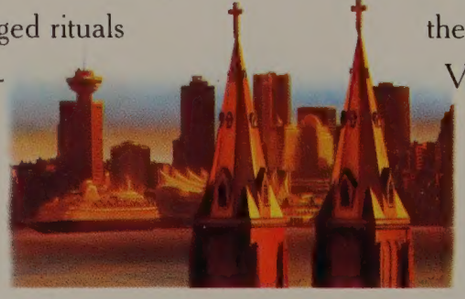
For here the supernatural abides in all that is living.

The mountaintops and salmon streams. The mighty rainforests. The towering cedars, clover meadows and subtle scent of blossoms. The deer, the bear, the seal – the creatures that are the Animal People.

And our link to another realm.

Taking wing with what seemed to be a small berry in his beak, Raven ascended into the thick black sky. With but a quick flick of his head he cast out the sun, unveiling all he had created in a wave of daylight.

Surely, it's for these very good reasons so many of our native peoples, like the Tsimshian, the Tlingit, the Haida, all chose to settle here. And still the beating rhythms of unchanged rituals pay tribute to everything that made it a reality.



Now, if all this stirs the spirit of adventure in you and your kind, please, be our guest.

Experience the strength of our homage in the totem poles that have long stood the test of time.

Or in museums and galleries thousands of years in the making.

Vancouver, Canada's third largest urban centre, stakes its roots with a park the size of some cities. Architectural designs – like 'Canada Place' – echo its mountainous backdrop. While our many cultures add their own vari-

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meet such interesting souls.

ations on the performing arts.

And thank heaven for the ocean. Yes, the Whale, the Sea Otter and the like still play. But in harmony with cruise ships, ferries, sailboats, seaplanes – and one floating symphony.

On Canada's west coast. Because, when life itself is inspiration, you never know whom you might meet.

And from high overhead, the Raven smiles.

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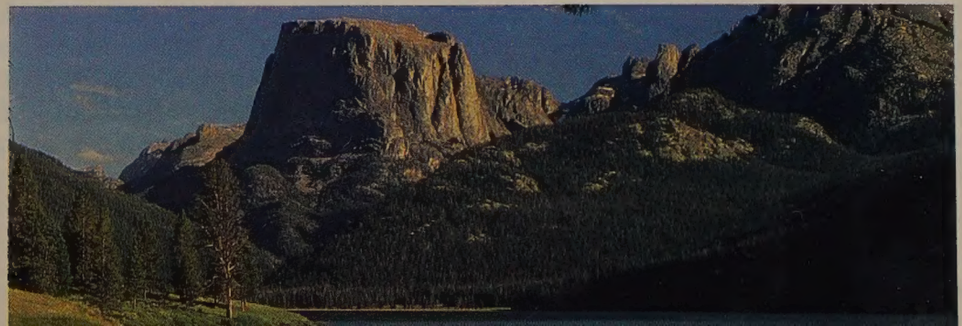

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LETTERS

A CORPORATE DINOSAUR

In "The Dinosaurs of Winter" (April 1991) the full-page illustration at the end of the article includes a creature that the caption identifies as *Atlascopcosaurus,* but other than this one mention there is nothing in the article about the animal.

How a dinosaur came by such an unusual name is fully as interesting as the mystery of how the animal became extinct, because embedded in that multisyllabic tongue twister is the name of a large, well-known manufacturer of pneumatic and hydraulic machinery for the construction and mining industry—Atlas Copco. Is the article's mention of excavation of dinosaur bones by "jackhammers, big drills, and explosives" a clue?

PETER MARGOLIN
New York, New York

THOMAS RICH REPLIES: The name *Atlascopcosaurus loadsi* Rich and Rich 1989 was given to a hypsilophodont dinosaur found at Dinosaur Cove and one other site along the Victorian coast to honor both an individual and a company. Mr. William Loads was then the head of Atlas Copco in the State of Victoria. Beginning in 1984, when the first tunneling was carried out at Dinosaur Cove, he provided the required equipment gratis. He continued to do so in subsequent years, a time when very little was recovered.

Since he left Atlas Copco a few years ago, the organization has continued to sponsor the work. Thus, when an opportunity came to honor both Loads and his company for their long-term support for the project, the opportunity was taken.

The reason no mention of *Atlascopcosaurus* was made in the text and the reason it is shown almost hidden in the scrub is that it was identified solely on dental material. There are limb bones of hypsilophodonts known from Dinosaur Cove that are clearly not *Leaellynasaura.* Someday, perhaps, a more complete specimen of *Atlascopcosaurus* will be found and the association between limbs and dental material will be firmly established.

The deduction from impressions found inside the fossil skull of *Leaellynasaura amicagraphica* that that creature had exceptional eyesight, essential to successful living in the lengthy night of its antarctic habitat, speaks for very highly tuned detective work by researchers. Whatever the visual acuity of that hypsilophodont, however, I believe it would have been hard put to see, on the shortest day of the year, the sun shining "briefly on the *southern* horizon at noon."

J. HOWELL PEEBLES, JR.
Tullahoma, Tennessee

Yes, the sun would have been on the northern horizon.—*Eds.*

SEA SYMPHONY KUDOS

As one who has pursued the leviathan for nearly four decades, I write to salute *Natural History* for the special section "Symphony Beneath the Sea" (March 1991).

When I first traveled to the Alaskan Arctic to record the bowhead in 1971, I thought that the bowhead must be a master singer because of its huge head, which makes up one-third of its body, and its need to navigate an ice-racked realm. We did pick up low utterances as the whales migrated northward in 1971 and again in 1973, but not the fabulous sonic repertoire that Christopher Clark has obtained over the past seven years ("Moving with the Heard"). Hats off to Clark for his keen observations and gifted pen.

Just as stunning is John Ford's extension of the late Michael Bigg's work on the system of vocal traditions whereby every killer whale pod can be identified ("Family Fugues"). He notes that "some pods use as few as seven or as many as seventeen discrete calls." The fact that killer whale pods are matriarchal offers interesting comparisons with elephants, which are also grouped in matriarchies of long lineage.

The conundrum posed by the global lexicon of dialects of the ubiquitous killer whale is as challenging as that offered by the Maya glyphs a generation ago, for here we have another cerebral species staying in touch through elegant signals.

SCOTT MCVAY
Princeton, New Jersey

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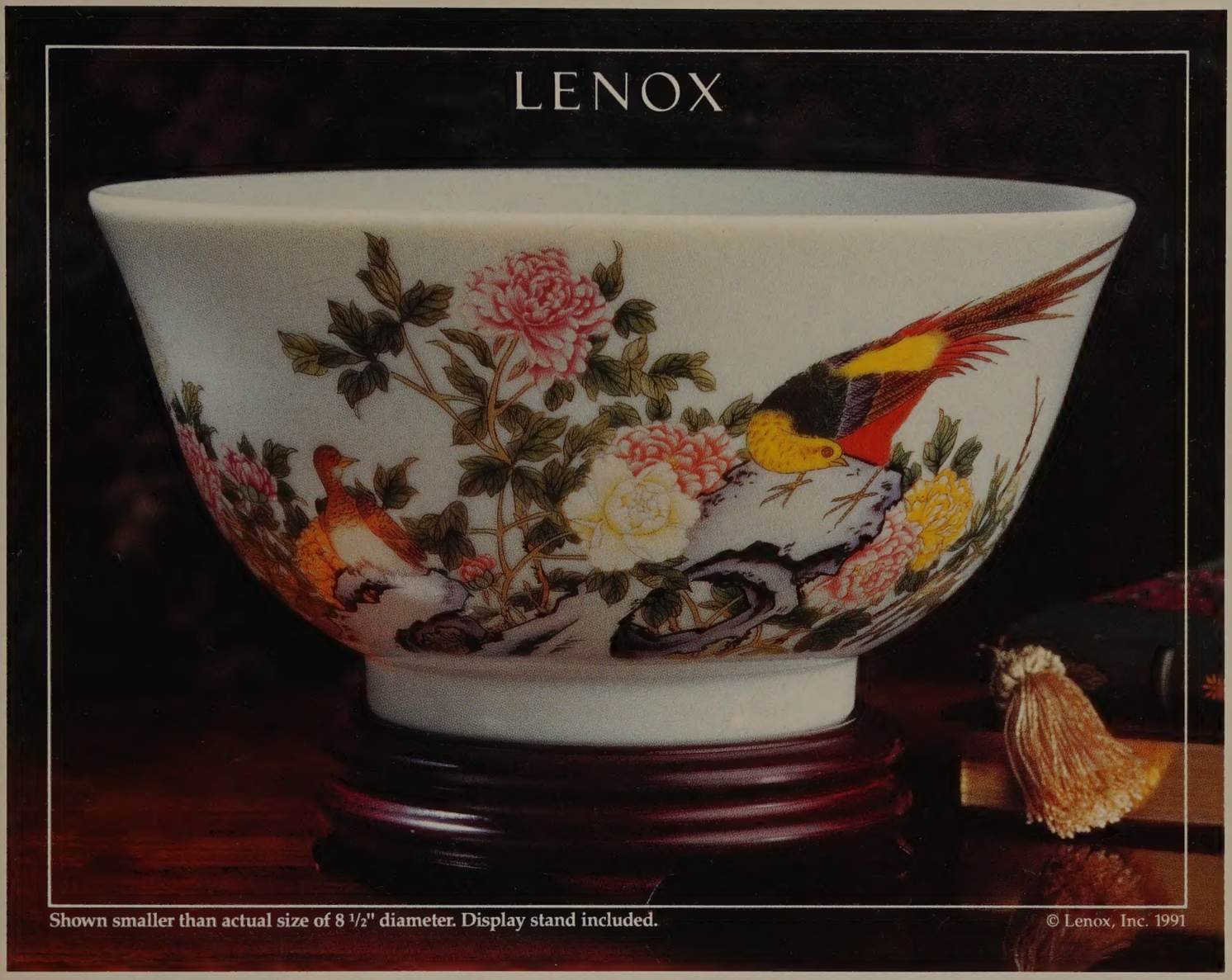

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Paper Route

Were the manufacture and use of bark paper introduced into Mesoamerica from Asia?

by Paul Tolstoy

Scenes on Maya painted pottery show scribes at work, confirming that books were an important part of Maya civilization at least 1,400 years ago and suggesting that the status of scribes in Maya society was high. But the first missionaries to reach New Spain regarded the native books as evil and burned all they could find. Only four Maya and possibly two central Mexican pre-Columbian manuscript volumes, or codices, survive (scholars are unsure whether the central Mexican examples date from before or shortly after the conquest). Occasionally, archeologists come across remains of other codices, but they are generally so decayed that they can be neither read nor restored.

The codices were made of bark paper, a material different from true paper, which was invented in China between 2,500 and 2,000 years ago (according to tradition, by the court official Ts'ai Lun in A.D. 105). The Maya and Mexicans used bark paper not only to write on but also for ceremonial clothing, banners, fans, bags, and other items. Thus, it can equally well be termed bark cloth. But what technically distinguishes it from true paper is not the way it was used. People can write on bark paper or cloth, as the Maya did, or make clothes of true paper, as the Chinese did. The important difference lies in the manner in which the two are manufactured.

Bark paper or cloth is a layer of inner bark, or bast, taken from a tree, often of the fig family. It is widened, thinned, and made flexible by beating, sometimes in combination with other techniques, such as soaking in water. In the end, it retains much of the original structure of its naturally interconnected fibers and thus remains, essentially, a sheet of bark. True paper, too, can be made from the inner bark of trees and in earlier times often was. But in the process, the bast is boiled and pounded to a pulp, losing its natural structure. It is then re-formed into artificial sheets by being drained and dried on a screen.

Examination of Maya codices shows that although their pages were not formed on a screen, the bark was very thoroughly worked, its fibers rearranged to a degree that brought it very close to true paper. Despite a scarcity of evidence, research during the past hundred years has given us some idea of how Maya bark paper was made in pre-Columbian times, when and where it first appeared in the region, and its possible origin. Much of this work concerns papermaking in central Mexico, but the results apply to the Maya as well.

This is the fifth in a series of articles that explore recent findings and interpretations concerning the rise and fall of ancient Maya civilization.

As early as 1888, German archeologist Max Uhle published illustrations of certain stone artifacts from Mexico and the Maya area, identifying them as tools for beating out paper from the bark of trees. His identification was based on their resemblance to examples, which he illustrated beside them, from the island of Sulawesi (Indonesia). At the time, scholars had ample evidence of the tools' present-day use in Asia, where it was recorded by ethnographers, but the application in the New World was purely inferential. A breakthrough came in 1900, when ethnographer Frederick Starr discovered such tools being used for bark-paper making among the Otomí and their neighbors in northeastern Mexico.

Starr described how the women of the village of San Pablito made bark paper and cut out paper effigies for magical and ceremonial purposes. His report, although brief, strongly suggested that the Otomí were making their paper by techniques inherited from their pre-Columbian ancestors. His findings were later confirmed by others, including the writer-explorer Victor Wolfgang von Hagen, who in 1943 brought together most of the information then available in his book *The Aztec and Maya Papermakers*.

In particular, von Hagen brought the attention of scholars to an account written in about 1571 by botanist Francisco Hernández, who had witnessed native papermaking in Tepoztlán, Morelos, some fifty years after the conquest. He also added his own account of a related procedure observed among the Sumu, jungle dwellers of eastern Honduras, at the other end of Mesoamerica. Soon after, in 1948, Hans Lenz put together what remains the most authoritative study of the technology of native Mesoamerican papermaking. Lenz, the owner of a Mexican paper mill, combined his own numerous and detailed observations in the field with laboratory studies and an exhaustive survey of museums and of the literature.

The "bark beater" that the Otomí papermakers use today is a small, flattish, quadrangular stone slab with parallel grooves on one or both faces. Holding the tool in one hand, they beat the wetted bark on a board. Similar stones are found at Mesoamerican archeological sites, and their shape has long suggested (as it did to Uhle) that they were the heads of composite tools, originally set in hafts of perishable material, perhaps twigs bent to grip the stone heads on their edges. This was indicated, in particular, by the channels or corner notches invariably found on the stones' narrow sides and whose only con-

In this Maya sculpture from Copán, a monkey scribe dressed in a loincloth holds the tools of his trade.
Justin Kerr

ceivable function is to receive a handle. Francisco Hernández's sixteenth-century account also describes just such a composite device, which I have called the racquet type of bark beater.

Only in 1961, however, did direct evidence of such hafting become available. In that year, archeologist Richard S. MacNeish, digging in the dry cave of El Riego, in the Tehuacán valley of south-central Mexico, recovered a racquet beater, dating from about A.D. 700, that still retained its original handle. It consisted of a long loop of bent wood encasing a stone head. The two ends of the loop were drawn together by a ligature of twisted fiber. Wear marks on the wood, according to MacNeish, indicate the former presence of two additional ligatures and an enclosed end piece at the grip end.

MacNeish's find strikingly resembled an artifact restoration proposed in the 1920s by Marshall H. Saville, a curator of Mexican antiquities at the American Museum of Natural History. Inspired by Uhle's 1888 publication, Saville had taken as his model a bark beater used in recent times by the Toradja, a group who inhabit Sulawesi, and attached a similar handle to a Mexican specimen from Mitla, an archeological site in southern Mexico.

A parallel between Mesoamerican and Asian artifacts also exists in the case of a second type of bark beater, a one-piece, longitudinally grooved club. It is less frequent than, but equally as widespread as, the racquet type at ancient sites in Mesoamerica and is the type still used by the Sumu in Honduras. In Asia, its archeological distribution overlaps that of racquet beaters in Sulawesi, the Philippine Islands, Taiwan, and Vietnam. In Sulawesi, such beaters, often made of wood, still serve today in a sequence of beatings, in which they are used first and racquet beaters are used later. And club beaters are well known to ethnographers as the bark cloth (tapa) beaters of Polynesia.

My own survey of hundreds of specimens of the club and racquet types shows further correspondences in the construction of Mesoamerican and Indonesian examples. On both sides of the Pacific, for instance, we sometimes find diagonal grooving and patterned alternations of deep and shallow grooves on the working faces of racquet heads. My research also reveals a pattern of dates for the archeological examples. In Mesoamerica, the earliest bark beaters are from the Maya area and its periphery, particularly the Pacific coastal plain of Guatemala and El Salvador, where they appear some 2,500 years ago. Subsequently, they occur throughout Mesoamerica, seemingly later as one moves farther westward and eastward, away from the Maya regions. The dating of artifacts from the islands of Southeast Asia is less secure, but both forms almost certainly go back several hundred years earlier than they do in Mesoamerica. In Taiwan they probably go back one or two thousand years still earlier.

The existence of similar artifacts on both sides of the Pacific Ocean—representing a technology that appeared 4,000 or 5,000 years ago in Asia and then 2,500 years ago among people in Mexico and Central America—raises the question of their connection. Are they the result of independent invention or of the migration of people or ideas—what anthropologists call diffusion? This problem was first put before me in 1950 by the late Gordon F. Ekholm, a curator of Mexican antiquities at the American Museum of Natural History, who, like Saville before him, was impressed by the near identity of specimens from Mesoamerica and Sulawesi.

To deal with that question, I set out to compare manufacturing procedures in the two regions and to understand the steps (necessary or optional) that are part of these procedures. I have sought to identify the technical problems solved at each step and to learn what other possible solutions to them exist, both in theory and in actual

Otomí Indians in the village of San Pablito, Mexico, pound bark into paper. While assembling a grid of thin strips is a local development, the use of grooved stone beaters and other features of papermaking resemble practices in Asia.
James Dow, Oakland University

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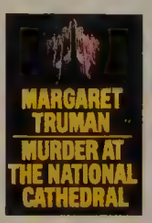

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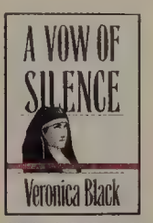

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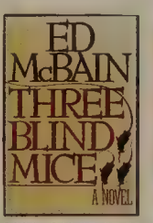

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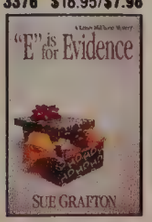

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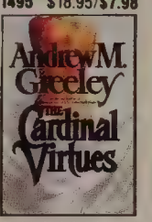

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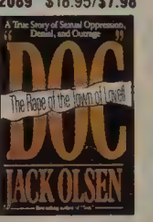

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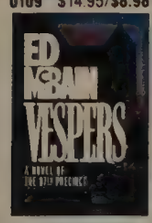

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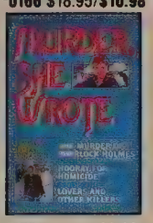

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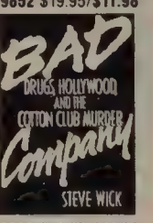

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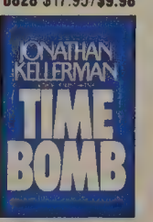

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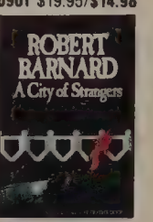

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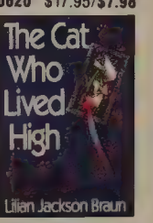

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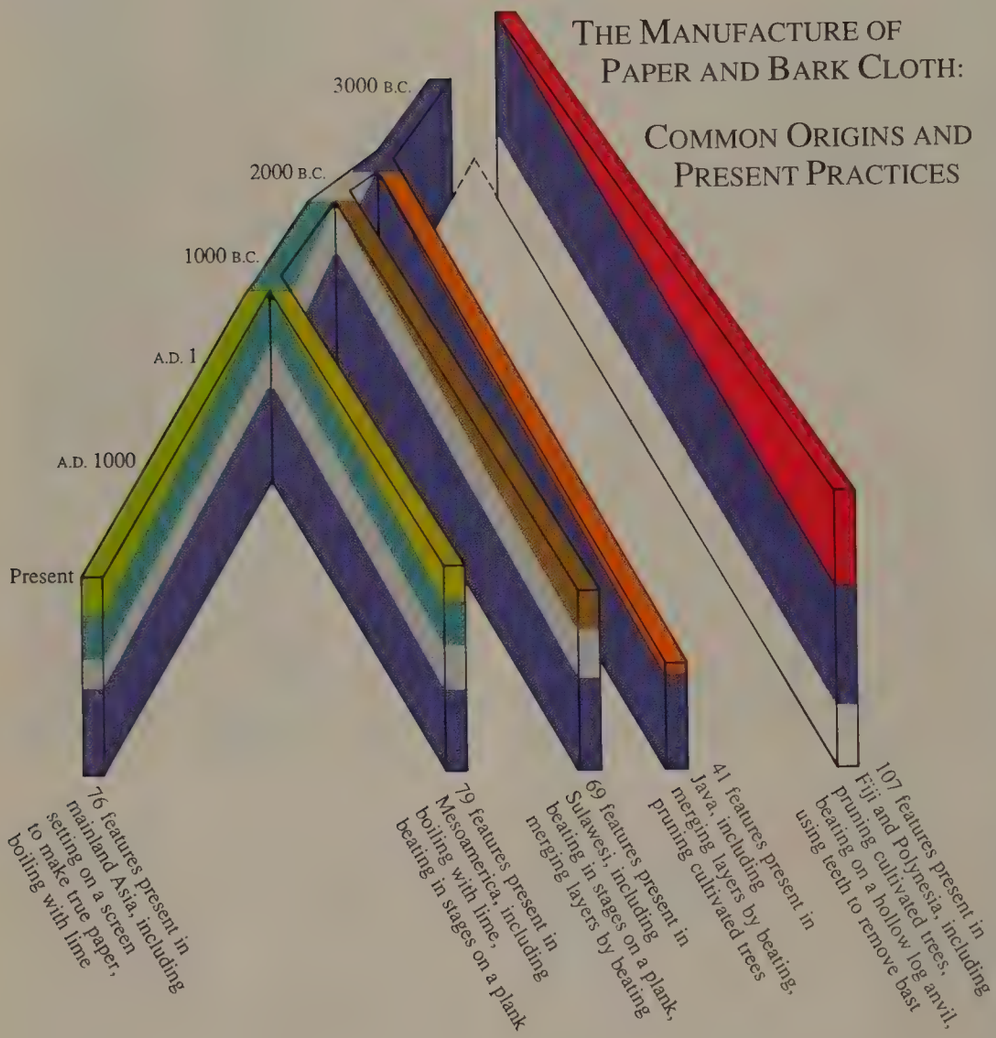
practice worldwide. Only with such a perspective can scholars hope to distinguish those features of a technology that are determined by recurrent technical constraints (and therefore likely to arise repeatedly and independently) from those that recur because their practitioners are adhering to a previously existing recipe.

Surveying the manufacturing technologies of bark cloth and early true paper worldwide, I have identified some 300 variable features in the steps that go into producing these materials. They include such elements as the cultivation or care of trees used for their bark; ways of getting at the desired bast layer and separating it from the trunk and the outer bark; soaking or boiling the bast at some stage of manufacture; addition of ash or other substances to the water in which the bast is soaked or boiled; beating the bast on a log, stone, plank, or specially made anvil; hanging the finished product to dry or stretching it out on the ground; joining sections by sewing, felting, or gluing; adding other materials such as cotton cloth, gum, or mica flakes; and undertaking such further treatments as painting, stamping, and fringing.

In addition, I have recorded some 140 uses of the product, such as mats, blankets, bags, various items of clothing, shrouds, banners, and of course, writing paper. I have noted incidental social or ritual practices of the manufacturing process, such as whether the manufacturer is traditionally male or female, whether offerings are made as part of the procedure, and so on. Finally, there are some 100 specific details of the design of bark beaters, which may be combined in various ways, and a mass of relevant botanical and linguistic information.

As a result of this research, I have reached three principal conclusions. The first is that, bark beaters aside, the Toradja of central Sulawesi and the Mesoamerican communities share ways of making and using bark cloth that are as numerous and as striking as the similarities between the tools they use. They have in common techniques and sequences of peeling the bark off trees; separating the bast from the rough outer cortex; softening the bast by boiling it with ashes; beating it on boards, first with a preliminary beater, then with tools whose grooves are progressively finer at each step; and using the finished product as writing paper, as festoons used in rituals, and in payment of taxes or tribute. Some of the elements are very rare in the world and are found only in these industries and their close relatives. All have functional alternatives, and few, if any, are absolutely determined by the mere goal of making bark cloth.

The second point is that there is a well-defined cluster of Southeast Asian technologies—including Javanese bark-paper making, bark-cloth making in central Sulawesi, and true papermaking (as practiced in Indochina, China, Taiwan, Japan, and elsewhere). As a whole, this cluster of technologies is quite homogeneous and contrasts clearly with other Southeast Asian and Indonesian technologies. Measured against the range of technologies found around the world, Mesoamerican procedures also fit within this cluster. The resemblances are especially strong both to Asian true papermaking (although the definitive technique of forming sheets of paper in a tray or frame is absent) and to bark-cloth making in central Sulawesi. In short, Mesoamerican papermaking qualifies as a member of one family of Southeast Asian bark cloth and paper industries. Its direct connection to them would be unproblematical were it not for its geo-


THE MANUFACTURE OF PAPER AND BARK CLOTH:
COMMON ORIGINS AND PRESENT PRACTICES
3000 B.C.
2000 B.C.
1000 B.C.
A.D. 1
A.D. 1000
Present
76 features present in mainland Asia, including setting on a screen to make true paper, boiling with lime
79 features present in Mesoamerica, including boiling with lime, beating in stages on a plank
69 features present in Sulawesi, including beating in stages on a plank, merging layers by beating
41 features present in Java, including merging layers by beating, pruning cultivated trees
107 features present in Fiji and Polynesia, including pruning cultivated trees, beating on a hollow log anvil, using teeth to remove bast

The technologies for making bark cloth and paper found in recent times in certain regions of Asia, the Pacific, and Middle America include shared features that suggest a common origin. Based on the array of features (aside from bark beaters) observed in each region, a family tree can be constructed that shows when the ancestor of each technology may have branched off. In the diagram, each color represents a group of features that arose together and then persisted, in varying proportions, in later technologies. Mesoamerican practices seem closely allied to those of mainland Asia and Indonesia and more distantly related to those of Polynesia.

Peggy Conversano

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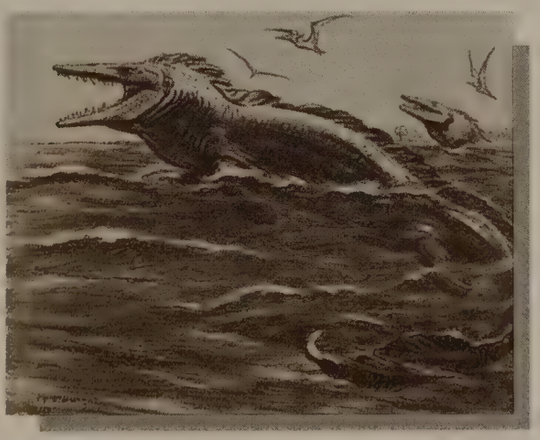

Mosasaurus
Cretaceous Era

ntosaurus*
sic Period

Archaeopteryx and Pterodactyl
Jurassic Period

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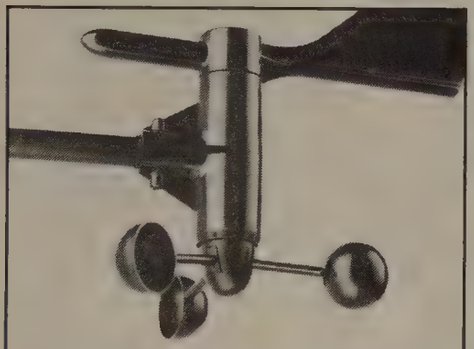

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graphical location. Incidentally, other American technologies, notably those of Amazonia and southern Central America, are different in most ways and provide no hint of a common background or history with Mesoamerican papermaking.

Finally, the shared features and innovations suggest a family tree for these industries with a history of common inheritance and local differentiation. In it, Mesoamerican paper technology evolves from a prototype shared with Sulawesi bark cloth and moves toward the threshold of true papermaking. Evidence from China suggests that this threshold was crossed sometime between 2,500 and 2,000 years ago, possibly in southern China or Indochina. Mesoamerica, however, acquired a version of the technology as it existed just prior to this event, probably from the area that includes Indochina, Taiwan, and the Philippine Islands, where the two beater forms occur together archeologically. By the time ethnographers reached the area, the craft had disappeared, its place taken by weaving and true papermaking.

All this points to the direct transfer of technology from Southeast Asia to Mesoamerica, apparently by a sea voyage that took place about 2,500 years ago. Contrary to what some might expect, Polynesian tapa making—perhaps the most elaborate set of procedures ever devised to make bark cloth—does not provide a credible link between the Indonesian and Mesoamerican technologies. For one thing, archeology suggests that the outer fringes of Polynesia (including Hawaii, the Marquesas, and Easter Island, the closest landfalls to the Americas) were still undiscovered and unoccupied at the time when they might have served as stepping stones to Mesoamerica. More important, Polynesian technology itself, al-

A sampling of club-shaped bark beaters, from left to right (approximately one-third actual size): recent wooden beater from Honduras, stone beaters from pre-Columbian Mexico and Guatemala, Neolithic stone beaters from Vietnam and the Philippines, late nineteenth century wooden beater from eastern Indonesia.
AMNH

though related to that of island Southeast Asia, appears to have branched off earlier than Mesoamerican papermaking.

Polynesian tapa making has its own distinctive characteristics, such as the use of a hollow wood anvil, and lacks many key features that link Java and Sulawesi to Mesoamerica, notably the unique racquet beater with a stone head, unknown in the Pacific east of the Philippines. The eastward progress of tapa making appears to have been relatively slow, particularly after it reached Fiji, and the technology was probably introduced into easternmost Polynesia by its first settlers no more than 2,000 years ago.

Students of Native American civilization have been reluctant to face the implications of these findings for many reasons. To some, the difficulties are concrete and practical. How is one to visualize a voyage 2,500 years ago that was almost impossible for Spaniards in the 1500s? Why did it leave no archeological traces in the intervening islands of the Pacific? Why should castaways, if such they were, carry with them and introduce the technology of papermaking? Why don't we have other evidence of their arrival?

Plausible answers exist for all these queries. Although we know little about it, navigation in the China Sea 2,500 years ago may have been more effective in some ways than that of the sixteenth-century Spaniards and Portuguese. There are also excellent geographical and navigational reasons why such travel might have left no traces in the Pacific islands. The winds and currents of the Pacific Ocean north of the equator force ships sailing from the Philippine Islands to Mexico's west coast to take a route well north of Hawaii, with no island stopovers (this route was discovered by the Spaniards in 1565 and, until 1815, was used by the *Manila Galleon,* which brought Chinese silks and porcelain to Acapulco in exchange for silver). As Thor Heyerdahl, of *Kon Tiki* fame, noted many years ago, it is a route as short in miles as any farther south, although our flat maps fail to convey this, and because of the Japanese Current, it is actually shorter than alternatives in miles of "surface water."

The travelers who brought papermaking to the New World may not have been

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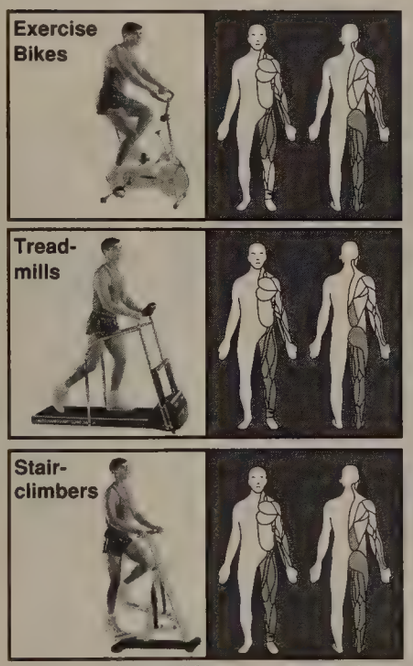

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Richard S. MacNeish

Two racquet-type beaters collected early this century from central Sulawesi (left, less than half-size) compared with two Mexican examples, a beater (ca. A.D. 700) from the Tehuacán valley and a pre-Columbian beater head from the state of Oaxaca.

castaways at all, but explorers or deliberate settlers. They may even have been Mesoamerican returnees, strongly motivated to get home after an intentional or unintentional trip westward to Asia, which was favored by prevailing winds and currents. Finally, there is other evidence of transpacific contact, although it is all controversial. Among this evidence are certain features of the Mesoamerican calendar—especially the ordered list of twenty day names—that David H. Kelley, of the University of Calgary, believes were borrowed from Asian sources.

For other skeptics, the issue is primarily one of methodology. Since the 1930s, it has been unfashionable to use ethnographic data, as I have done, to construct schemes of cultural relatedness or to infer past events. The problems that comparative ethnographic studies were designed to address, however—those of the history of prehistoric and preliterate societies—are still before us. There is a wealth of relevant information contained in ethnographic materials that can be profitably integrated with our now greatly expanded archeological knowledge.

Finally, and perhaps most often, the objections are theoretical. For decades, archeologists have cultivated a view of human societies as self-contained, localized systems, whose evolution is largely determined by needs and causes that are, if not internal, at least local in origin. In this vision, there is little room for input from the outside. Even when grudgingly recognized, introduced foreign elements are most often seen as powerless to modify the strong chains of cause and effect that connect local environments, local economies, local social and political systems, and even local ideologies.

The best that can be said of such a view is that it is shortsighted. It may be difficult, at this point, to assess the degree to which Asia and Mesoamerica were indeed interconnected in pre-Columbian times. If our thinking on this matter is to progress, however, we must be prepared to admit that some contact could have occurred. We must also cease to proceed as if contact and borrowing are always inherently negligible as a cause of significant change. Only then will we transcend such antiquarian pursuits as the comparison of papermaking or calendars and seriously address the greater questions: Was Maya civilization different as a result of contact with Asia, and if so, how different? □

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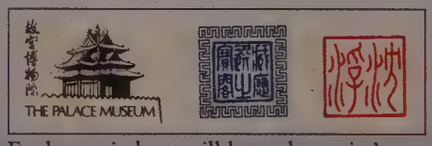

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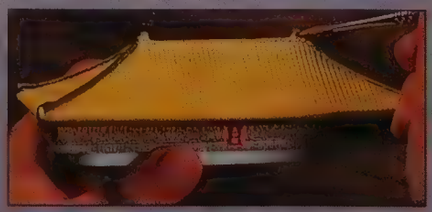

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And the Cat Shall Lie Down with the Rat

Garbage heaven is a peaceable kingdom for two legendary enemies

by James E. Childs

Four cats and three large rats were feeding side by side from an overturned trash can in a dimly lit, filthy alley in one of Baltimore's worst neighborhoods. It was 1:00 A.M., and any people out that late would have heard me muttering disjointed sentences into a tape recorder or chortling with joy at discovering a malodorous rat in one of the traps I had carefully placed under a rotting mattress or next to a mountain of waste-filled plastic bags.

Because I have made cats and rats the object of serious study, many people regard me as a trifle touched. Even fellow biologists look askance at me when I show slides of my study sites at scientific meetings. Aren't cats pets and rats little more than city pigeons with fur? What can they offer in terms of ecological insight?

This is an attitude I understand. I have not always been an urban ecologist, but only turned to this environment after my plans to investigate foraging behavior in pollen-feeding bats were dashed by limited funding. At the suggestion of my Ph.D. adviser, Edwin Gould, I looked into the possibilities of studying urban cats. To my astonishment, a perusal of the literature on their ecology revealed almost nothing. Until relatively recent studies by Jane Dards, formerly of England's University of Bradford, and Carol Haspel, of New York's LaGuardia Community College, urban cats were forgotten or ignored animals, in part because of their unglamorous surroundings.

I began roaming the streets to observe how free-ranging cats—feral cats and strays, as well as house cats allowed to wander freely—make a living in a city. Because cats are active at night, I was mostly involved in nocturnal study and immediately found myself confronting another common denizen of the city's seamier places, the brown, or Norway, rat. My interest was piqued when I watched these mythical enemies feed peacefully from the same garbage heap, drink from one puddle, and nonchalantly pass each other on well-worn, shared paths. Here was the potential to study the interactions of two species usually cast in a predator–prey struggle. This had the makings of a classic ecological drama, but with a twist—it was played on grim city streets and starred little-known actors.

James E. Childs

On a Baltimore street, an indifferent cat looks the other way as a large rat passes by.

Both cats and rats hold prominent positions in human mythology and history. As guardians of the grain stores, domesticated cats were sacred in ancient Egypt. Norway and black rats, on the other hand, have been credited with causing more human deaths as carriers of disease than all the world's wars and revolutions combined. The cat's role in suppressing such villains was well worth investigating; its public health significance added to its ecological interest.

As the epitome of predator and prey, the pair have been inextricably linked in history and fable. In the eighteenth century, Frederick the Great of Prussia required a levy of cats from conquered towns to protect his grain stores from rodent vermin. In the nineteenth century, the British Post Office allotted a portion of its budget to maintaining cats on its premises to control mice and rats.

The cat's legendary abilities as a rat catcher have not been universally accepted, however, and only in the last forty years or so have scientists begun to study the relationship between these animals. In 1953, British ecologist Charles Elton reported that farm cats would not necessarily clear a farm of existing rat infestations, but that they could keep buildings free

from rat reinfestations once the existing rat populations had been eliminated by some other means, such as poison. Elton's conclusions were only inferential, however. He compared rates of reinfestation on farms with and without cats. In 1957, biologist David E. Davis, of Johns Hopkins University, found that barnyard cats on Maryland farms delayed the spring increase in rat numbers (associated with renewed breeding activity after a winter lull) and hastened the population decline in the fall (when reproductive activity again slowed down). In 1951, another Johns Hopkins scientist, William B. Jackson, examined cat feces for rat remains and concluded that individual urban cats removed an average of twenty-eight rats per year off the streets—at most, 20 percent of the number needed to keep rat populations under control.

Thus, for all the storied fame of cats killing, eating, and otherwise abusing rats, scientists had little to say on the subject; outside of the laboratory, few people had described natural encounters of cats and rats, much less the act of predation. I was determined to see for myself cat and rat interactions in the alleys of Baltimore.

First I had to pinpoint places where both species existed in large enough numbers to make my observations meaningful. I visited the Baltimore City Animal Shelter to find out where shelter wardens removed the most dead cats from the streets. With what I hoped was a map of hot spots for free-ranging cats, I drove through those alleys and streets at all hours of the night counting the cats I saw. Not only did the map serve admirably in leading me to locations with large numbers of cats; to my surprise it was equally suitable for predicting where the most rats were to be found. Only later did I come to appreciate how opportunistic both species

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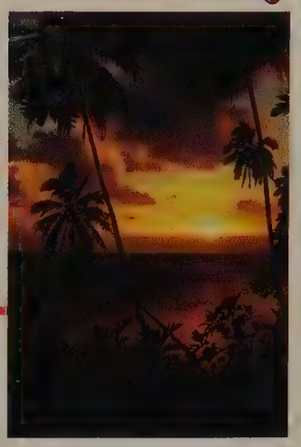
Exploring Polynesia



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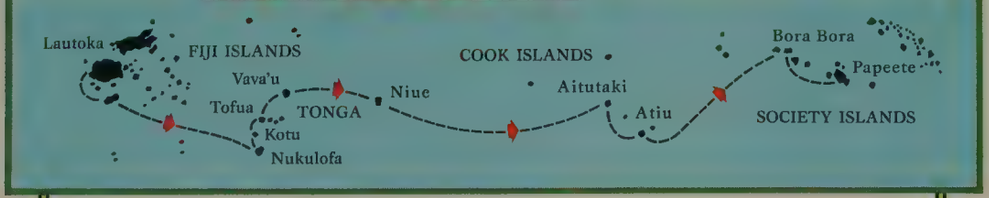

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are, living almost exclusively off the bounty of human refuse.

At night, I used my car as a blind to watch for interactions between cats and rats. By parking near street lights, I could accurately record whatever happened within about fifty feet. Witnessing cats killing rats turned out to be remarkably difficult, and in more than a thousand hours of watching cats and rats together, I saw only five kills. I also needed to study the victims, but capturing them turned out to be equally trying; cats often took off with their prey when they saw I was interested. After prolonged chases on foot, I recovered only three rats.

Then I realized that a large number of people in the neighborhood with a soft spot for the down and out were feeding free-ranging cats. (Later, in a door-to-door survey, I found that approximately 16 percent of city residents do.) Because cats sometimes reward their benefactors with fresh kills, I enlisted the support of neighborhood cat fanciers who were willing to collect and save the odd pieces of rat that showed up on their doorsteps.

I knew that in the process of weaning, when the litter is about four weeks old, cats bring prey to the nest to introduce kittens to solid foods. I located the dens of several feral cats and added to my collection of rat samples in this way. Because many of the victims consisted only of inedible leftovers, such as heads, feet, and tails, I trapped live rats to establish criteria for sizing and aging my growing collection of rat parts. I could compare these trapped rats with those killed by cats.

The results of the data from my prey collections were unequivocal. Yes, cats did prey on rats, but exclusively on small rats that weighed less than seven ounces. My trapped population of rats from the same alleys averaged almost fourteen ounces, and some weighed in at more than a pound and a half. About one in ten weighed less than seven ounces, and they were juveniles, too young to have reproduced. Removing a small number of them would have a minimal impact on rat populations.

With this information, I decided to expand my studies of rat ecology to parks in Baltimore. Although within the city limits, the areas chosen for detailed studies approximated rural settings because they were not frequented by people, nor was refuse available. Perhaps these results would bear out the traditional view that cats control rat populations. With fellow Johns Hopkins researchers Greg Glass and George Korch, I trapped live rats in both habitats; then examined, measured, and tagged them before releasing them where they had been captured. Later, when we recaptured marked rats, we computed and compared growth rates.

The results showed that a rat's size at a given age depends upon where it lives. Inner-city rats are relative giants; males and females weigh an average of 40 percent more than, and grow twice as fast as, their parkland cousins. Rats of identical weight in inner-city and park areas are of very different ages because park rats take a much longer time to reach a given size. We also calculated rat longevity from recaptured, tagged animals and found that life expectancy is nearly identical for rats from both habitats.

We also discovered something else when we examined the reproductive characteristics of rats: sexual maturity depends on size rather than age. Females can become pregnant once they reach a weight of about 7 ounces, regardless of how old they are and whether they live in alleys or parks. Male rats also showed sexual maturation upon reaching 7 ounces. This means that park rats reach reproductive maturity later than those in the streets. Females weighing between 7 and 10.5 ounces have litter sizes of eight, while females weighing between 14 and 17.5 ounces average thirteen young. (The very largest females, weighing more than 18 ounces, produce litters of ten, which indicates that reproductive capacity probably tapers off with size and age.)

Well-provisioned rats in inner-city locations with lots of high-energy garbage are huge compared with those from park locations with poorer pickings. As early as 1949, Davis raised rats from both urban and rural environments in his laboratory and found that given equal rations, individuals grew at identical rates and reached comparable adult size. In documenting size variation in natural populations, we confirmed Davis's studies, showing that differences depend upon habitat and not genetic variation.

The suitability of garbage as a food source for urban rats was explored in 1950 by Martin Schein and Holmes Orgain, of the Johns Hopkins School of Hygiene and Public Health. This pair collected more than 45,000 pounds of garbage from one

In Gustave Doré's 1868 wood engraving, the cat maintains its legendary role as rat catcher.

The Granger Collection

residential block over a five-month period. They then sorted the trash into manageable samples and established that more than 30 percent of the material, by weight, was potentially edible by rats. City rats were then trapped by the investigators and offered samples of fifty of the most common items found in the garbage. The rats preferred such garbage food items as scrambled eggs, macaroni and cheese, cooked corn kernels, and virtually any of the raw vegetables to standard laboratory rat chow. The authors concluded that the amount of edible and available garbage was well in excess of the needs of the street rats. Although the garbage preferences of feral cats have not been studied in such a rigorous fashion, recent studies have shown that cats esteem garbage as a source of food as much as rats do.

So what are the implications for free-ranging cats and their traditional role as rat catchers? If cats kill rats only within a limited size range, then a parkland rat that takes six months to reach seven ounces has a considerably greater risk of being eaten than does an inner-city rat that reaches this size in three months. In addition, the faster-growing city rats will begin reproducing earlier and produce more young over a given life span. Thus, cats are probably far more effective in controlling rural rat populations.

We can hypothesize that over the course of human history, the role of the cat in controlling rats has changed dramatically. In the agrarian past, Norway rats presumably resembled the smaller rural animals of today, and their populations would have been more readily limited by cat predation. With urban development, the rat has grown fat off the excesses of human refuse and therefore is increasingly protected from the influences of predation. In addition, an energy-rich, constantly replenished food supply has provided the urban cat with an irresistible alternative to the hard life of a predator. Like bears that have become addicted to garbage in tourist areas of national parks and forests, inner-city cats have become dependent on refuse. Although we regard the problem of garbage accumulation and disposal as an environmental dilemma, we might also consider, if only in passing, its effect on a legendary predator–prey relationship.

James E. Childs is an associate professor in the Department of Immunology and Infectious Diseases at the Johns Hopkins University School of Hygiene and Public Health, where he studies diseases that cats, rats, and other animals transmit to humans.

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On the Loss of a Limpet

A small snail gets a dubious honor and gives us an important warning

by Stephen Jay Gould

Darwin marveled at the abundance of giant Galápagos tortoises when he visited the islands in September 1835, but he also noted a marked decline based on ease of human exploitation for food. (Ships would often take tortoises away by the hundreds, stacking them live in the hold to provide months of fresh meat "on the hoof." The tortoises were essentially defenseless. As a single barrier to capture, Darwin noted that ships usually sent out hunting parties in pairs, and two men could not lift the largest animals.) Darwin wrote in the *Voyage of the Beagle:*

> It is said that formerly single vessels have taken away as many as seven hundred of these animals and that the ship's company of a frigate some years since brought down two hundred to the beach in one day.

Although not threatened as a whole, the species is much depleted today, and several distinctive forms, once limited to single islands, have disappeared. I saw the saddest story of this legacy—Lonesome George, the last individual of the saddle-backed race from Pinta Island. No mate has been found for George, although the island has been scoured. He has been moved, for safekeeping (and in an apparently vain hope for salvation of his kind), to a research station on Santa Cruz Island, where I saw him several years ago. He is well fed and surely pampered, and he may live for another century or more; but his lineage, at least as a pure pedigree, is already extinct.

Every George must have his Martha. The last passenger pigeon, also a mateless vestige of a doomed race, died in the Cincinnati Zoo on September 1, 1914. Martha's body was taken to the Cincinnati Ice Company, suspended in a tank of water, frozen inside a 300-pound block of ice, and sent for extrication and stuffing to the Smithsonian Institution, where she resides today.

The Galápagos tortoises were vulnerable and restricted in geography; their extreme reduction and partial extinction merits no special surprise. But how could the superabundant and widespread passenger pigeon crash and die within a century? By some estimates, they were once the most common bird in America. They migrated in huge flocks over most of eastern and central North America. Pioneer ornithologist Alexander Wilson estimated one such aggregation as containing more than two billion birds. One colony in Wisconsin spread out over 750 square miles. The famous testimony of Audubon himself, made in Ohio just 100 years before Martha's death, not only locates human rapacity as the cause of eventual decline but also depicts the fabulous abundance:

> As the time of the arrival of the passenger pigeons approached, their foes anxiously prepared to receive them. Some persons were ready with iron pots containing sulphur, others with torches of pine knots; many had poles, and the rest, guns.... Everything was ready and all eyes were fixed on the clear sky that could be glimpsed amid the tall tree-tops.... Suddenly a general cry burst forth, "Here they come!" The noise they made, even though still distant, reminded me of a hard gale at sea, passing through the rigging of a close-reefed vessel. The birds arrived and passed over me. I felt a current of air that surprised me. Thousands of the pigeons were soon knocked down by the polemen, whilst more continued to pour in. The fires were lighted, then a magnificent, wonderful, almost terrifying sight presented itself. The pigeons, arriving by the thousands, alighted everywhere, one above another, until solid masses were formed on the branches all around. Here and there the perches gave way with a crack under the weight, and fell to the ground, destroying hundreds of birds beneath.... The scene was one of uproar and confusion.... Even the gun reports were seldom heard, and I was made aware of the firing only by seeing the shooters reloading....
>
> The picking up of the dead and wounded birds was put off till morning. The pigeons were constantly coming and it was past midnight before I noticed any decrease in the number of those arriving. The uproar continued the whole night....
>
> Towards the approach of day, the noise somewhat subsided. Long before I could distinguish them plainly, the pigeons began to move off.... By sunrise all that were able to fly had disappeared.... Eagles and hawks, accompanied by a crowd of vultures, took their place and enjoyed their share of the spoils. Then the author of all this devastation began to move among the dead, the dying and the mangled, picking up the pigeons and piling them in heaps. When each man had as many as he could possibly dispose of, hogs were let loose to feed on the remainder.

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In 1805, passenger pigeons sold for a penny a piece in the markets of New York City. By 1870, the birds were still reproducing only in the Great Lakes region. Hunters used the newly invented telegraph to inform others about the location of dwindling populations. Perhaps the last large wild flock, some 250,000 birds, was sighted in 1896. A gaggle of hunters, alerted by telegraph, converged upon them; fewer than 10,000 birds flew away. The last wild passenger pigeon was killed in Ohio in 1900. The few zoo colonies dwindled, as keepers could never induce the birds to breed regularly. By 1914, only Martha remained.

These sad, oft-told tales are canonical stories of the extinction saga: defenseless populations composed of individuals that are easy to find and profitable to kill. Restricted compass on an island is the surest path to destruction—the dodo or tortoise model. But even a large, continental range will not save a vulnerable population—the passenger pigeon model.

One environment, however, has been seen as a refuge for at least most kinds of organisms: the open ocean. Here, or so the argument goes, geographic ranges are usually large enough, and ecological tolerances sufficiently broad, to prevent rapacious humanity (or any other agent of extinction) from getting every last one. Populations may be beaten way back, but a few survivors will always manage to find a refugium.

This argument about the oceans is as old as modern biology itself. In the first great document of evolutionary theory, published in 1809, Lamarck tried to deny extinction altogether (in his theory of creative response to perceived needs and inheritance of characters thus acquired, organisms should evolve fast enough to overcome any environmental danger). But Lamarck did allow an exception for conspicuous species on land. Even "Lamarckian" response cannot be quick enough or extensive enough to overcome the most powerful and efficient agency of environmental disturbance—human depredation. Lamarck wrote (*Philosophie zoologique,* chapter 3):

> If there really are lost species, it can doubtless only be among the large animals which live on the dry parts of the earth; where man exercises absolute sway, and has compassed the destruction of all the individuals of some species which he has not wished to preserve or domesticate.

But small, inconspicuous oceanic species should be immune from our influence:

> Animals living in the waters, especially the sea waters . . . are protected from the destruction of their species by man. Their multiplication is so rapid and their means of evading pursuit or traps are so great, that there is no likelihood of his being able to destroy the entire species of any of these animals.

We would downplay Lamarck's optimism about the oceans today. Conspicuous species of large organisms with small populations are vulnerable—and several fishes and marine mammals, including Steller's sea cow, have succumbed. But Lamarck's distinction and prognostication have held. The ledgers of death in historical times do not include marine invertebrates.

Extinction ranks only with Baghdad, the Civil War, and the decline of Yuppiedom as an "in" topic for our current season. We are so used to hearing tales of destruction, so inured or even numbed at this point, that we expect almost any species, anywhere in the world, to be the next victim (but don't hold your breath for rats, cockroaches, and mosquitoes). We have engraved the notion of fragility upon our souls.

But step back from all these accounts of death and think for a moment: have you ever heard about the extinction of a marine invertebrate species, even among widely exploited lobsters, scallops, or conchs? We may drive a local population of marine invertebrates to death, but never an entire species. Many years ago, in this forum, I told the sad story of *Coenobita diogenes,* a large Bermudan hermit crab, now apparently doomed because the only shell large enough to hold its body, the whelk *Cittarium pica,* was eaten to destruction on Bermuda. (The crabs now eke out a tenuous existence within fossil *Cittarium* shells eroded from Bermudan hillsides.) I was deluged with suggestions for salvation. One man offered to design a plastic *Cittarium* and to ship them by the thousands for distribution on Bermudan beaches. I was touched by his ingenuity and generosity, but a much simpler and more effective solution exists. *Cittarium pica* is extinct on Bermuda, but not elsewhere. This species is eaten with gusto on most West Indian islands, and piles of empty shells are stacked on beaches and roadsides. Any enterprising savior of *Coenobita* could easily fill a boat and bring the real McCoy back to Bermuda.

In short, Lamarck was right, and his distinction of sea and land has much to teach us about the general phenomenon of species death. By our records and reckoning, no marine invertebrate species has become extinct during historical times. (Geological extinctions, of course, occur at characteristic rates over millions of years—thus illustrating the immensity of difference between our time and earth time.) Geerat Vermeij, a leading expert on oceanic life and its vulnerability, wrote in 1986 that "marine invertebrates are relatively immune from extinction." So Lamarck was right—that is, until February.

The February 1991 issue of the *Biological Bulletin,* the technical journal published by the Marine Biological Laboratory at Woods Hole, contains an article on the demise of the eelgrass limpet by James T. Carlton and four other authors (including my good friend Gary Vermeij, who must now eat his words or be happy that he wrote the disclaimer "*relatively* immune from extinction").

Limpets are snails with an unusual mode of growth. Snail shells are cones that expand slowly and wind around an axis as they grow, thus producing the conventional corkscrew of increasing width. But the limpet cone expands so rapidly that the shell never winds around its axis for more than a fraction of a whorl. Thus, a limpet shell looks like a Chinese hat of the old caricatures. The large open end clamps tightly down upon a rock or a food source, and this power of adhesion has made the limpet a symbol of tenacity and stubbornness in many languages and cultures. In England, for example, limpets are (according to the OED) "officials alleged to be superfluous but clinging to their offices."

Lottia alveus, the eelgrass limpet of the western Atlantic, once lived in fair abundance from Labrador to Long Island Sound. Although this geographic range should be broad enough to win the usual marine immunity from extinction, two peculiar features placed the eelgrass limpet in a rare category of vulnerability. First, as its name implies, the eelgrass limpet lived and fed only on a single species of plant, *Zostera marina.* (*Zostera,* a biological oddity in its own right, is one of the few marine genera of angiosperms, or ordinary flowering plants. Most people assume that all marine plants are algae, but a few of the most typical and "advanced" flowering land plants have managed to invade the oceans, usually forming beds of "sea grass" in shallow waters.)

L. alveus had a long and narrow shell, just wide enough to fit snugly over a *Zostera* blade. The limpet fed exclusively on epithelial cells of the sea grass. The fate of *Lottia* therefore depended upon the health of *Zostera.* Moreover, *Lottia* had an unusually narrow range of physiological tolerance, particularly for changes in salinity. This limpet could not survive any marked departure from normal oceanic salinity of some thirty-three parts per

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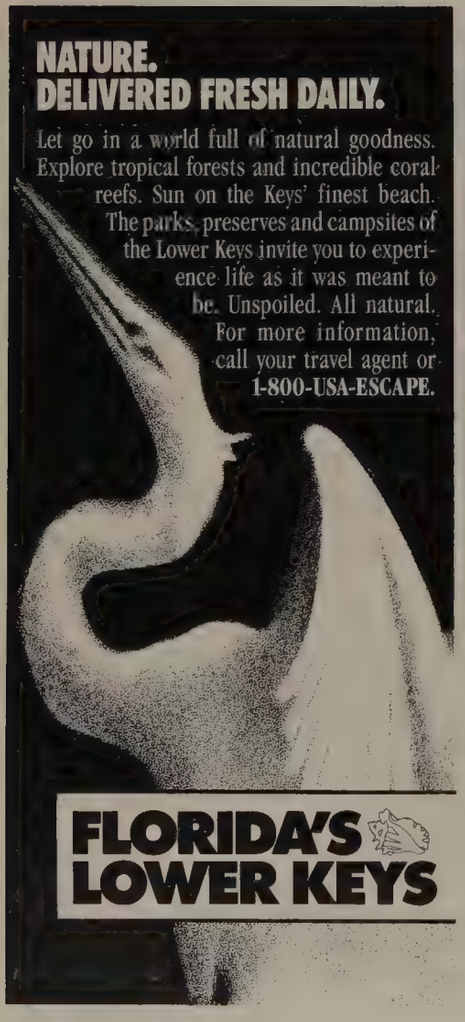
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FLORIDA'S LOWER KEYS

thousand, whereas *Zostera* spans a much broader range and can live in brackish waters of much reduced salinity.

Both *Zostera* and *Lottia* originated in the Pacific Ocean and invaded the North Atlantic in late Tertiary times (just before the ice ages), as many other species did, through the Bering Strait and along the Arctic Ocean. Populations of *Lottia* remain in both the eastern and western Pacific, so the entire genus is not lost. (Taxonomists are still debating the status of *Lottia.* Some regard the three populations—eastern Pacific, western Pacific, and extinct Atlantic—as fully separate species; others as subspecies of a single, coherent group. In either case, the Atlantic populations were distinct in form and color and clearly represented some degree of genetic differentiation.)

Atlantic specimens of *Lottia* were reported as abundant by all collectors from first extensive descriptions of the mid-nineteenth century through the 1920s. The last living specimens were reported in 1933. From the early 1970s through 1990, the five authors have searched diligently for *L. alveus* throughout its former range. They also looked in fourteen major museum collections for specimens gathered during the past fifty years—and found none that could be verified. They even searched through several herbarium collections of *Zostera,* hoping that dried limpet shells might be found on the pressed sheets. (Museums often preserve reference collections of plants by flattening them onto sheets of paper later bound into books.) Again, no *Lottia* could be found. This diligence certainly merits our assent to their preliminary conclusions that *L. alveus* is truly extinct in the Atlantic.

But why did *Lottia* gain the dubious honor of first marine invertebrate to disappear during historical time? Carlton and coauthors have also provided a coherent and satisfying explanation that neatly combines a specific historical event with the general biology of *Lottia.* Between 1920 and 1933, *Zostera* virtually disappeared from both the eastern and western Atlantic Ocean. This species of sea grass has suffered numerous declines throughout its recorded history, but none nearly so severe as this accidental correlate with economic depression on adjacent lands. (No, I will not try to link the collapse of the stock market with the simultaneous decimation of marine grasses.) The cause of this near wipeout has been debated for years, with disease and environmental fluctuation as leading contenders. A series of articles published during the 1980s has decisively implicated a marine protist, the slime mold *Labyrinthula* (a unicelled creature that aggregates to form temporary colonies), as chief culprit. Infestation by the pathogenic species of *Labyrinthula* leads to the formation of small black patches on *Zostera* leaves. The patches spread, eventually causing death and detachment of the entire blade.

This massive die-off of *Zostera* led to marked changes in associated ecosystems, including a great reduction in migratory waterfowl populations and the loss of commercial scallop fisheries. But neither *Zostera* nor any of these ecological dependents became entirely extinct. *Zostera* itself thrives in a much wider range of salinities than the pathogen *Labyrinthula* can tolerate. All populations of normal marine salinity were completely destroyed, but *Zostera* can also live in brackish water, while *Labyrinthula* cannot. Thus, relict *Zostera* populations hunkered down in low salinity refugia, and the species survived. Other species associated with *Zostera* also pulled through, either because they could also tolerate the low salinities of *Zostera* refuges or because they could live on other resources, although often with much smaller populations, while *Zostera* was absent. When *Zostera* returned after the *Labyrinthula* epidemic subsided, these other species reflowered as well.

But consider the cruel fate of poor *L. alveus.* This limpet lacked the flexibilities of all other species associated with *Zostera. Lottia* could not hunker down with *Zostera* in the low-salinity refugia because this limpet could only live in normal marine waters. And *Lottia* could not switch to another host species because it ate only the epithelial cells of *Zostera* blades. For *Lottia,* the total disappearance of *Zostera* in waters of normal salinity meant complete destruction. *Zostera* returned, but no *Lottia* remained to greet the renewed bounty.

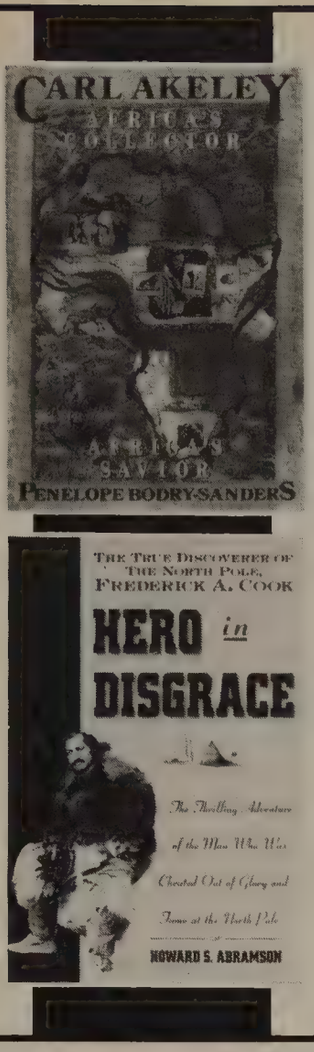
The tale of *Zostera* and *Lottia* is one story among millions in natural history. Why choose to tell it in this forum? To merit report among a plethora of alternatives, stories must either be good enough in themselves or illustrative of something more general and interesting.

To begin with generalities, we might ask what the story of *Zostera* and *Lottia* can tell us about our chief parochial concern with the subject of extinction—anthropogenic assault on the biosphere and consequent loss of biodiversity. The answer, I think, must be "rather little." *Lottia* was no Galápagos tortoise or passenger pigeon, a creature hounded to death by human hunters. *Lottia* didn't even fall victim to some unintended consequence of human disruption in natural

habitats. In fact, *Homo sapiens* probably had nothing at all to do with the death of *Lottia* (I doubt that one person in a million ever laid eyes on the creature). *Lottia*'s extinction was an ordinary natural event, the kind that, summed through geological ages, produces the basic pattern of life's history. Epidemics are as intrinsic as water and sunshine in the history of life. They don't usually wipe out a species entirely (as the *Labyrinthula* epidemic spared *Zostera*). Yet species clearly have differential susceptibility to extinction, and some factors of weakness enhance the possibility of death in epidemics. Natural selection can only work for reproductive advantages of the moment and cannot overtly protect a species against unexpected vicissitudes of time. Many strengths of momentary selection engender a potential for later extinction as an unintended and detrimental side consequence. So long as *Zostera* bloomed and seas stood at normal salinity, intense specialization may have aided individual *Lottia*. But such narrowly committed forms are usually the first to go when unusual circumstances wipe out a highly specific habitat, even temporarily. Marine species are relatively immune from extinction because few have such narrow commitments; but *Lottia* was an exception in its intense specialization—and it paid the usual price.

If *Lottia* has a message for the anthropogenic theme, I would only propose a status as a symbol. As the first species to die (during historical times) in the one habitat that, from Lamarck to last February, seemed free of such danger, *Lottia* must stand as a warning and an emblem—as the Crispus Attucks of a potential wave in the most protected arena if our environmental assaults worsen. Didn't British power laugh at the ragtag rebellion when Attucks and four others died in the Boston Massacre of 1770? As a warning, *Lottia* attains the status of a good story in itself. As an emblem, *Lottia* wins the greatest generality of all. Most crises start with something small, something virtually beneath notice. But whispers soon grow to whirlwinds. Limpets, with their low profiles and large apertures (often serving as suction cups for attachment), are metaphors for tenaciousness, for hunkering down in times of trouble. How appropriate, then, as a warning against complacency, that a real version of this symbol should be the first species to die in a realm of supposed invulnerability.

Stephen Jay Gould teaches biology, geology, and the history of science at Harvard University.



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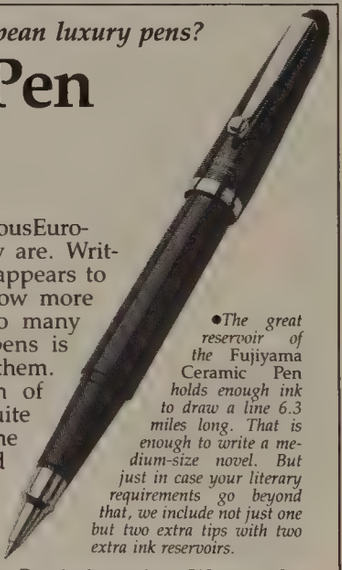

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Like Every Place You've Never Been

by Stephen Pruett-Jones

In the course of Bruce Beehler's fifteen-year adventure in New Guinea he had a lifetime of experiences, and in *A Naturalist in New Guinea,* he writes about them for a lay audience. More than a chronological account of what Beehler did and saw, the book attempts to convey and explain, through personal experience, why field biologists do what they do, why studies of behavior and ecology are important in understanding the evolution and diversity of life, and why New Guinea is so intriguing.

Although a history major in college, Beehler was a precocious ornithologist and field biologist. His senior undergraduate thesis, *Birdlife of the Adirondack Park,* was published as a book and remains an important regional field guide. Such early promise was not overlooked, and Beehler won a Watson Fellowship, a sort of MacArthur award for undergraduates—to do what you want, anywhere you want, and see where it takes you. In Beehler's case it took him to the South Pacific and New Guinea in 1975, and once there, he was hooked—as is almost every biologist who visits the island. A second book, *Upland Birds of Northeastern New Guinea* (Wau Ecology Institute, 1978), quickly followed Beehler's first trip to New Guinea, and a third, the field guide *Birds of New Guinea,* coauthored by Thane Pratt and Dale Zimmerman (Princeton University Press, 1986), followed his graduate work. Coming so early in his career, Beehler's contributions to New Guinea ornithology have set him apart and put him next in line in the progression of great naturalists who have worked in New Guinea in this century: Ernst Mayr, Stanley Rand, Thomas Gilliard, and Jared Diamond.

A NATURALIST IN NEW GUINEA, by Bruce M. Beehler. *University of Texas Press, $26.95; 256 pp., illus.*

For a trained scientist, the transition from writing technical papers and books to writing accounts of personal thoughts and feelings is a difficult one. Beehler, to his credit, succeeds as well as anyone who has attempted this transition, and those areas where he does not succeed are minor or simply reflect that there is still much to be written about the lives of field biologists. We are still waiting for someone to tell our story as Garrison Keillor has for Norwegian bachelor farmers.

The book is exciting because New Guinea is exciting and because Beehler had some amazing experiences there. He describes for us his original research on more than a dozen species of birds of paradise, and he takes us from lowland forests to high-altitude moss forest and alpine grasslands, to Irian Jaya (the state of Indonesia comprising the western half of the island) and several satellite islands. His was not the average experience of an American student working in New Guinea. By his own admission, Beehler has "all the impatience genes an American can inherit," and this impatience manifested itself in an almost frenetic approach to his research and travels. When he heard about a possible new species of bird on Goodenough Island, he was on a plane headed there within a matter of days; when he learned that there was an accessible population of the pale-billed sicklebill in Papua New Guinea (the independent commonwealth comprising the eastern half of the island), he organized an expedition to study it. Realizing that no one had made careful observations of Macgregor's bird of paradise, he found a population in the remote alpine peaks of the central mountains and the funding to do a study on them. Beehler took advantage of any opportunity that provided the possibility for ornithological discovery.

The book is also instructive. Besides the accounts of his own actions, Beehler describes the work of other scientists and includes vignettes on rain forest ecology and conservation, the justification for collecting specimens, island biogeography, and the culture of Papua New Guinea. Beehler writes for a lay audience and does it well; he explains technical terms, instructs the reader as to field methods, and

Photographs by Bruce M. Beehler

Subalpine forest on Mount Bangeta

Photo: Reuters/Bettmann

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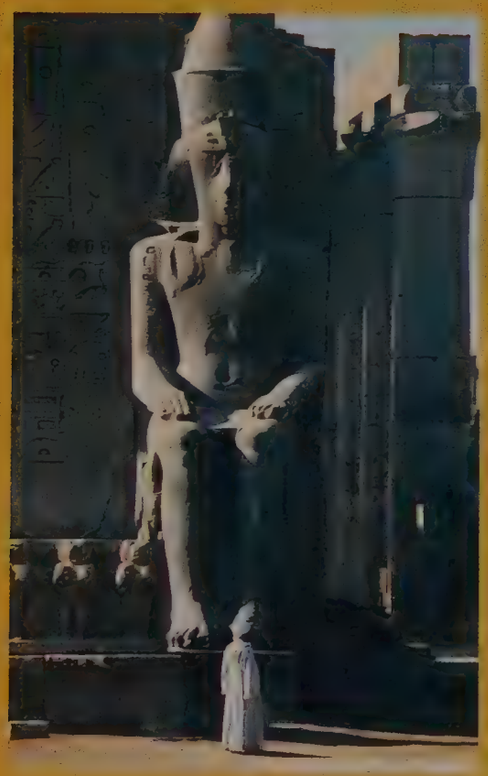

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deciphers complex ecological relationships and evolutionary ideas. Nonetheless, there are a few inconsistencies in this approach. Beehler goes so far as to describe mist nets and to explain that snooker is different from billiards, while at the same time using such phrases as "a low level of outcrossing, to reduce genetic load" without further explanation. The only other places where his style fails him, where the prose is rather stiff and curt, are where he lapses into what I would call "journal mode." These criticisms are minor; the book is easy to read and enjoyable, and educated and professional audiences will also get much from it. If I had read this book as an undergraduate, I would have been spellbound by the accounts and the realization that one person could do so much in such a short period of time. I would have been inspired to run off to New Guinea to begin my own adventures.

My only disappointment in the book was what was not included. Living in New Guinea, particularly as a field biologist working with local people, one has countless small but significant and memorable personal experiences. For example: learning pidgin English and realizing that to say the word *birthday* you must say the entire phrase *de mama bilong mi em karim mi*—"the day my mother gave

Male bird of paradise displaying to a female in the canopy of a tree

birth to me"; talking to a woman in a village and having her giggle hysterically when you ask her name; learning that men in Papua New Guinea like to put the testicles of opossums in their shirt pocket because it gives them a "*gutpela smel*"—good smell; eating witchety grubs for the first time; observing the strength, stamina, and fortitude of Papua New Guineans, both women and men. And talking to an old man who remembers seeing his first airplane or European, while his grandson stands by his side with a boom box wanting to discuss the latest Bruce Lee movie. To use the phrase of AirNiugini, the national airline, New Guinea really is like "every place you've never been." From my perspective, I would have liked *A Naturalist in New Guinea* to contain more of these types of personal revelations and anecdotes. Beehler includes some of them—seeing the rain forest for the first time; the thrill of thinking you have just caught a new, undescribed species of bird; trying to figure out the difference between the pidgin English descriptions (here translated) for "distance": "a long way little," "a long way," and "a long way true." But I wish there were more; they make for wonderful reading and help convey the human side of the work that biologists do. Every scientist who has worked in New Guinea has had them, and they are what make being a naturalist there different from being a naturalist anywhere else.

The book is also as much a historical record of the biologists who worked in New Guinea during the 1970s and 1980s as it is a description about being a naturalist there. During his travels, Beehler came into contact with most of the other biologists working in New Guinea, and his accounts are an important contribution to the history of research during this period. With respect to American students, the bird of paradise and bowerbird cadre consisted of Thane Pratt, Bruce Beehler, Melinda Pruett-Jones, and me. We all worked on Mount Missim, either concurrently or in succession.

As Beehler describes it, Papua New Guinea is changing rapidly and in ways that make it increasingly more difficult for students and other workers to attempt what he did. Social unrest is rampant, and working in the field is increasingly dangerous. When Melinda and I began our work on Mount Missim in 1980, living in a forest camp was perfectly safe and our preferred accommodation. By 1987, through experiences it would take a book to describe, we feared for our safety in the field and were spending approximately 10 percent of our research budget on security guards. Although the lure of the mountains and the birds will, I suspect, pull me back there, one cannot at present consider long-term research in New Guinea without taking precautions.

If the societal situation improves and dedicated naturalists are permitted the opportunity to realize their passion for New Guinea's flora and fauna, everyone will benefit—New Guinea's citizens as well as people everywhere with an interest in this most fascinating of places. With more than 70 percent of its forests remaining intact, and not a single species yet known to have been lost to extinction, Papua New Guinea still has something—one might say everything—to conserve and protect, and the opportunity remains to do it right. *A Naturalist in New Guinea* highlights why it is so important that the effort succeeds.

Stephen Pruett-Jones is an assistant professor in the Department of Ecology and Evolution at the University of Chicago. Together with his wife, Melinda, he worked for eight years on birds of paradise and bowerbirds in Papua New Guinea.

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For butcherbirds, the message is a grisly medium

by Sarah A. Sloane

In the cool mist of a November dawn in northern Florida, a bird the size of a robin jets from a telephone wire and disappears into the tall grass below. A moment later, it pops up and lands on a nearby strand of barbed wire with its prize: a newly hatched hog-nose snake. With practiced skill, and its hooked beak, the bird wraps the serpent around a sharp barb. Within a few seconds, the snake, still thrashing, is impaled behind the head.

As the sun rises and the mist clears, a startling sight, typical of these open sandhills, meets the eye. For about ten feet in each direction, twenty-six additional victims, each neatly skewered on a barb, attest to the hunting prowess of the small predator—a loggerhead shrike. The open-air mortuary includes racerunner lizards, crickets, grasshoppers, beetles, and even a leaf. All but one of the animals—a brilliant green scarab beetle—are dead, but only a few have even begun to be devoured. This particular shrike, a male I knew well, had worked fast. Just two days earlier, I had removed and identified twenty-eight items from his "larder."

For the next few weeks, I continued to monitor this male's collection of prey. By catching and impaling an average of one item a day, he easily replaced the few that disappeared. I was struck, however, by the condition of the small animals that remained. Some were completely dried out, and others were rotten or teeming with ants. Why did this bird fail to replace these apparently no-longer-appetizing items with fresh prey? The task would certainly have been within his hunting capabilities, considering the speed with which he restocked in the two days after I stole his entire cache. I began to wonder if the shrike's array of quarry served as more than the food storehouse that many have often assumed it to be.

A native of North America, the loggerhead ranges from Mexico to southern Canada, while the northern shrike is found in more northerly reaches of the continent and is common and widespread throughout Eurasia, where it is known as the great gray shrike. Belonging to the genus *Lanius,* Latin for "butcher," these birds, like most others in the family of true

A great gray shrike picks at a hefty house sparrow skewered on a thorn.
Roland Mayr

Shrikes avail themselves of all kinds of prey within their ranges, but when in season, insects form a major portion of their diet. A bull-headed shrike, endemic to eastern Asia, right, manipulates an impaled mantis. Remnants of a kangaroo rat, below, dangle from a loggerhead larder in a shrub in the American Southwest.

Wade C. Sherbrooke

Tadashi Shimada; Nature Production

shrikes, are characterized by their habit of impaling or otherwise permanently securing prey that is occasionally still alive and kicking. The habit has given rise to such derogatory, if descriptive, common names as butcherbird (the United States), Jackie hangman (South Africa), murdering-bird (England), and the strangler (Germany and Israel). The name "shrike," derived from "shriek," refers not to the cries of the victims but to the shrike's own unmusical vocalizations.

To "impale," a shrike finds a suitable pointed projection, such as a thorn, or seeks out the forking branches of vegetation. Holding the prey in its bill, the bird executes a series of sweeping movements and eventually fixes its catch firmly by piercing it with the thorn or wedging it in the forking branches. Once the quarry is secure, the shrike tears it apart and eats it or simply abandons it, temporarily or permanently. Sometimes, uneaten portions of prey, such as the relatively inedible head of a bird or the pelvis and tail of a lizard, remain on their stakes to rot. Individual shrikes usually have favorite impaling areas within their territories. These preferred impaling grounds are often conspicuous and contain a variety of items. In the desert of the American Southwest, shrikes often make use of the tough spikes of yuccas. The result looks somewhat like a Christmas tree hung with grisly treats.

Although related to the songbirds, shrikes resemble raptors, such as hawks and falcons, in several ways and are equipped with some weaponry that allows them to strike and quickly dispatch quarry their own size and larger. For example, like raptors, shrikes have acute eyesight, large, heavy heads, hooked bills, and a notch, or tomial tooth, in the beak. The last is thought to be a specialization for killing vertebrates; the tooth helps to dislocate the prey's neck vertebrae, the death blow most often dealt to small mammals and birds. Unlike raptors, however, shrikes do not have heavy talons.

Opportunists, shrikes will chase and take small birds on the wing and are quick and accurate in following them to cover in tall grass. They swiftly pounce upon small mammals they spot while silently surveying the landscape from a high vantage. Shrikes deftly snatch flying insects, sometimes devouring them in the air, and "desting" venomous insects, such as bumblebees, by rubbing their abdomens against a perch and squeezing out the poison in the manner of African bee-eaters.

In northern Florida, loggerhead shrikes are resident year round. Males and females behave alike during the late summer and fall, defending their own large,

open territories from one another and from all intruders. Defense involves driving away interlopers and singing from high vantage points, such as telephone wires and the tops of trees. Both the male and female impale during this time. Only in the early part of the breeding season (late winter) can the identically plumaged males and females be distinguished behaviorally. Males expand their territories, while females relinquish theirs and choose mates, often a neighboring male. Courtship is a long process involving chases, displays, and courtship feeding. The territorial boundaries of a neighboring, courting couple gradually dissolve, and the territories coalesce for the nesting season. For the remainder of the breeding season, the female does not sing and impales briefly only to dismember prey. The parents separate and establish adjacent winter territories after the second brood fledges, and the cycle begins again.

The nest, often hidden in a low oak or hawthorn, is built of twigs and lined with grass. The female lays an average of four speckled eggs and incubates them alone while the male continues to defend the territory and to provide the female with some of her food. When the eggs hatch, both parents feed the helpless nestlings until they are ready to leave the nest about eighteen days later. After fledging, the awkward young beg from their parents relentlessly and begin to playfully impale leaves and bits of grass. Soon they are hunting for themselves and impaling the real thing.

While a shrike may perfect its impaling

Impaled for days but left uneaten, the dried corpse of a chameleon in the Negev Desert of Israel may catch the eye of a female shrike.
Reuven Yosef

technique over time, the habit is an inherited one. Juvenile shrikes raised alone in captivity will attempt to fix prey on anything available, including their wire cages. The type of impaling implements at hand during this critical learning period will determine a shrike's impaling tendencies for life. Young shrikes raised in the vicinity of thorns favor impaling on thorns, while those that become accustomed to forked sites, for example, clothespins, prefer to wedge their prey. This preference remains so strong that a bird raised in captivity and released will return to its cage and a favored impaling implement within it to skewer its prey. In this way, falconers have trained shrikes to kill and retrieve small birds.

In the 1960s, ornithologist Tom Cade trained a northern shrike named Green to hunt from a portable cage and observed her forays in detail when he released her near Lake Peters on Alaska's North Slope:

> Green flew free around camp all afternoon. She caught many bumblebees on the wing, and I found a decapitated fledgling longspur, which she apparently killed when I was not watching. Again, I was impressed by how she bided her time and waited for the best advantage. On one occasion, she sat on top of a big rock high up on the alluvial fan. Many small birds—larks, Water Pipits (*Anthus spinoletta*), redpolls (*Acanthis* sp.), longspurs, and buntings—were excited by her presence and kept flitting about and calling fifteen to twenty yards away from the rock. When they flew by fast close to the rock, the shrike showed not the least inclination to chase; but this was not the case with a Water Pipit that came flitting straight toward the rock, headed up into the wind, so that it was slowed down. When it was about ten yards from the rock and still headed straight for it, the shrike suddenly attacked, and there was a long, down-wind chase of several hundred yards. The pipit finally escaped by ringing up over the lake and out-climbing the shrike. As the shrike turned away from the pipit, she caught sight of a bumblebee flying fully 100 feet up in the air and snatched it in her beak while executing a beautiful swooping pass.

But why do shrikes impale their prey? Anthropomorphic explanations popular in the past attributed the habit to the shrike's sense of "sport" or an inherent bloodthirstiness. Shrikes lack the strong feet and piercing talons characteristic of classic birds of prey, and one scientific theory, first advanced in the mid-1800s to explain why shrikes secure their quarry, maintains that the thorn, barb, or fork takes the place of grasping talons and helps the shrike to anchor and then dismember its victims. Other current explanations revolve around food storage. Shrikes may impale prey for later use in much the same way that squirrels bury edibles or acorn woodpeckers hoard nuts in "granary" trees. Such a cache may tide a bird over in times of hardship and provide nourish-

Females Seek Males with Ready Cache

by Reuven Yosef

From June 1987 to June 1988, I studied impaling in twelve northern, or great gray, shrikes in the Negev Desert of Israel, about thirty-five miles south of Beersheba.

Adult female and juvenile great grays depart their nesting grounds in the Negev right after the breeding season ends, leaving male shrikes alone on their approximately 150-acre territories for most of the year. During this time, the males exhibited a number of curious behaviors. Like loggerheads, they tended to impale in conspicuous places, and I saw Eurasian kestrels and little owls boldly steal food from shrike caches. The males would replenish their stocks right after the raptors left and continue to impale in the same obvious spots. I also noticed a seasonal trend: during summer, after the females and juveniles had dispersed, I found no more than 15 to 20 items in each cache. But from September to December, the shrikes added from 90 to 120 items, and stretches of barbed wire and thorny bushes were festooned with bodies. At the same time, the shrikes also included inedible objects, such as feathers, snails, and pieces of cloth, in their collections.

Convinced that the males were building up impressive caches to attract females, which would start arriving in January, I decided to test the idea. I removed the caches from some males' territories, increased the cache size of others by adding a variety of edible items, and simply monitored the number of prey in a third, control group. The results were predictable. Males with supplemented caches were seen with females a month earlier than were the control males; not surprisingly, males stripped of their caches remained bachelors and eventually abandoned their territories, disappearing from the study area completely. These results suggested that conspicuous larders did indeed attract females, and the bigger the larder, the better.

The Negev shrikes nested mainly in saltbushes and tamarisk trees. The pairs with augmented caches nested three times during the season, as compared with once or twice by control pairs, and almost doubled the number of offspring they fledged for that season. Perhaps early nesting simply gives a female more time for more broods. But I think that repeated nesting attempts may also be a direct result of the extra food in larger caches. During the courtship, incubation, and nestling stages, the male feeds his mate and the young both fresh food and impaled food from the cache. Since I added edible items to the caches, the females on these territories may well have been better nourished and perhaps could better afford the physical rigors of raising three broods. If so, a female's choice of a male with an impressive larder made good reproductive sense.

My study of the Israeli great gray shrike is a good example of a kind of time-dependent puzzle solving. During summer, the lone male guards his territory and hunts only for himself. He impales prey only if he succeeds in catching something within forty minutes of having eaten—the typical time required to manufacture and eject a pellet composed of the indigestible parts of the prey. At this time of year, the male appears to be interested only in short-term storage. But during autumn, he takes pains to enlarge his cache. Although the male eats from this cache when the weather is inclement or when hunting has been poor, he also impales inedible objects during this period, suggesting conspicuous consumption, or overkill. Females arrive in midwinter. During courtship the female almost never hunts and the male supplies her with food. She builds the nest almost completely on her own and incubates and performs all the nest sanitation duties until the young fledge. During these stages, the female impales only when she needs to dismember largish animals, such as snakes, mammals, or other birds. In mid-June, the female departs. The male is left to care for the last of the brood and is usually free of them by mid-July or the beginning of August. My being able to observe the full annual cycle of the desert shrikes paid off, for only early in the breeding season was it clear that caches are important displays.

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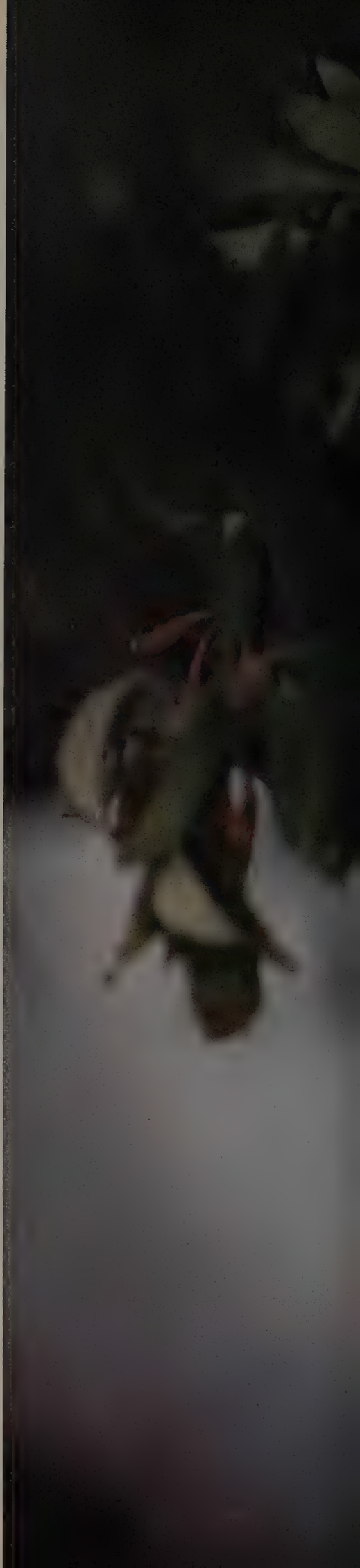
ment for females and young during the nesting period. Female shrikes have been observed to eat prey impaled earlier by their mates.

I first became interested in the question of why shrikes impale while studying them as a University of Florida undergraduate. For the loggerheads in my study site, the classic explanations of anchoring and caching fell short. My birds rarely impaled to tear prey apart and did not return to claim and devour abandoned prey even when temperatures were unseasonably cold. To further test this hunch, I carefully monitored all the objects impaled on a stretch of barbed wire that crossed through five shrike territories. I found that the birds did indeed "waste" food. Nearly half (48 percent) of the items were impaled whole and then abandoned untouched. Since I was able to keep close track of all items on the wire, in many cases I eventually documented their gradual disintegration and final disappearance. Nothing vanished inexplicably, and I never once observed any shrikes returning to previously impaled prey. In addition, although the morsels that the shrikes in my study site impaled were typical of what they were catching and eating, they did not impale hard-to-handle items more often than easily manipulated ones.

All the kinds and sizes of prey I found impaled had been easily grasped, killed, and eaten by shrikes at other times. Crickets were the item I found most frequently stuck on the barbed wire; surprisingly, I never saw shrikes in the process of impaling them, but I frequently observed the birds catching and eating them without any manipulation at all, other than breaking the crusty chitin with the bill. Thus, I had found some tantalizing evidence that, at least in northern Florida, loggerhead shrikes impaled a great deal of prey that was never going to be eaten. This led me to ponder other possible explanations for the remarkable impaling habit.

For several reasons, I suspected that impaled items were on display. The line of skewered corpses was unmistakable evidence of a shrike's presence, and they were fixed in conspicuous places, often on naked barbed wire, even when plenty of



A northern shrike prepares to dine on a freshly killed Wilson's warbler that it has wedged in forked branches.
Tom Mangelsen

cryptic spots were available. Since nothing else in the area impales, might the shrikes themselves be using impaled prey as a clear visual signal to other shrikes that the territory is already occupied by one of their kind? If impaling is a way of storing food, why don't the shrikes attempt to hide their goods, as do jays and squirrels, to prevent them from becoming a ready food source for other animals? (I did once see a northern mockingbird eat a cricket staked on a wire.)

My study area abounded in brushy hawthorns that were full of thorns and moderately leafy, even in winter. But even when the shrikes used these bushes, they generally staked their prey on thorns on the outside of the tree rather than in the relatively camouflaged interior.

Two other characteristics of shrike larders, in addition to their uniqueness and visibility, increased my confidence that they were used as visual displays. First, I occasionally found inedible objects impaled, including leaves and unpalatable grasshoppers. And finally, as I discovered in my inventory of one male's larder, the shrikes maintained a fairly constant number of impaled prey in their cache, regardless of the prey's condition.

I also witnessed male shrikes in two types of situations—driving away rivals and courting females—execute a display that seemed to mimic impaling: the male stood bolt upright and then "bowed," sweeping his bill along the ground or a perch. The possibility that this display derived from impaling movements intrigued me and reinforced my idea that impaling itself may be a display.

If so, a larder of impaled items may indicate to a rival shrike that one of its species has already taken up residence. Or an extensive stock of hefty prey may signal an exceptional domain or an exceptional male. By such advertising, a good hunter on a good territory may more easily attract a female and ward off male competitors than males with meager larders. Evidence that impaled items may indeed attract females comes from a recent, yearlong study of great gray shrikes, conducted by Reuven Yosef in the Negev Desert of Israel (*see* page 37).

Impaling probably serves different or multiple purposes depending on the shrike species, the region, or even the time of year. Both male and female loggerheads in Florida remain on their territories all year; they may have little need to stockpile food but a great need to advertise territory. Farther north, the need to cache food may be primary. Tom Cade found that northern shrikes, especially during the breeding season, fed heavily on the birds and mammals in their caches. Also, the size of available prey increases the farther north one goes, so in higher latitudes, impaling may be essential for anchoring some large catches before they are devoured. During the breeding season, only 7 percent of the loggerhead diet is made up of vertebrates, whereas northern shrikes dine on these large, hard-to-handle prey 23 percent of the time.

Did impaling first evolve as a visual display or as a means of anchoring prey or caching food for later use, or perhaps as a combination of all three? Although the question will never be fully answered, I find one scenario within the bounds of possibility. Laboratory studies have shown that impaling movements are innate and that shrikes deprived of impaling implements have a difficult time handling large prey. The ability to secure quarry may have allowed an originally insectivorous family of birds that lived mostly in the Old World tropics to move into colder areas where birds and mammals abound. No longer limited to small invertebrate foods and thus behaviorally suited to the temperatures of Palearctic regions, shrikes may have colonized Eurasia and eventually North America. In these more northern climes, caching would help sustain the birds when the weather was cold and food scarce.

Finally, because shrikes are unlikely to mistake the meaning of a conspicuous cache—that another shrike is present—impaling behavior may be an excellent example of an "exaptation," a behavior that arose in one context but now functions in another. Today, throughout much of the Northern Hemisphere and Africa, a "trophy rack" of tiny corpses is evidence that a shrike is at work. □

A late-instar gypsy moth larva
Mitsuhiko Imamori; Nature Production

The Multimillion-Dollar Gypsy Moth Question

The tree-destroying populations of the caterpillar rise and fall. Why?

by Jack C. Schultz

For the second time in a decade, oak forests on my farm in central Pennsylvania were as bare this past July as they were in January, thanks to the dancing poison moth, as the gypsy moth is known in China. In parts of Massachusetts, it may be the ninth or tenth time such devastation has taken place since 1869, when Leopold Trouvelot brought gypsy moth larvae from France to Medford, Massachusetts, in an ill-fated attempt to breed a better silkworm.

The gypsy moth caterpillar soon escaped from Trouvelot's home, and in 1889, the first major outbreak occurred. Leafless trees alerted people in the Boston area to the presence of an intrusive new resident (by the end of its eight-week life, the three-inch-long caterpillar is said to be able to eat more than a square yard of foliage). The population has since spread throughout Massachusetts and beyond at about fifteen miles per year; the insect's range now extends north into Quebec, west to Michigan, and south through Maryland into Virginia. Inadvertent transport of eggs by humans has established isolated gypsy moth populations in California, Oregon, and Washington, almost completing a global circuit from the insect's native Japan.

Outbreaks occur along an advancing front, after which the population declines for a decade or so before another epidemic occurs. During the intervening years, caterpillars can be so rare as to seem absent from the forest. But they are there. The few eggs and larvae that persist in the low-density years give rise to tens of millions of caterpillars that strip our forests in outbreak years. This buildup in numbers is spectacular; population density can increase three or four orders of magnitude in only two years. This means that in the course of two summers, egg numbers can explode from 100 to as many as one million per acre.

What causes these impressive outbreaks, and why do they usually collapse after only two to four years? This is a multimillion-dollar question in terms of lost recreational business (almost 13 million acres were defoliated in 1981 in seventeen northeastern states), the death of oak trees valuable to the furniture industry, and the cost of control efforts. For example, suppressing gypsy moth populations between 1979 and 1983 cost $24.2 million, an entomological battle second only to the expensive war against the eastern spruce budworm. Costs and the potential environmental consequences of applying pesticides over an ever-widening area suggest why there is ample economic interest in understanding the causes of gypsy moth outbreaks and declines.

Moreover, these outbreaks present one of the great mysteries of biology. Few species of forest Lepidoptera (moths and butterflies) have outbreaks, and few outbreaks last more than a couple of years. Various studies have pointed to vertebrate predators (cuckoos, starlings, grackles, mice, skunks), invertebrate predators (beetles, stinkbugs), and parasitoid insects (whose larvae develop inside gypsy moth

eggs, caterpillars, or pupae) as agents controlling gypsy moth populations. But these natural enemies cannot regulate the explosive growth of outbreaks.

Just a few years ago, a group of us at Penn State thought we were close to solving the mystery of gypsy moth population dynamics. We realized that host trees were not passive participants in the drama of gypsy moth outbreaks but fought back by releasing defensive chemicals, mainly phenols, into their foliage. These noxious substances (*see* "Tree Tactics," *Natural History,* May 1983) stunt caterpillar growth and the number of eggs the female moths lay. They also make each egg smaller, which reduces the growth of the next year's caterpillars.

Together with researchers Mary Carol Rossiter and Ian Baldwin, I tried to determine the connection, if any, between leaf chemistry and caterpillar population density. We raised gypsy moth caterpillars on bag-covered branches of forty-five red oaks and hired students to defoliate selected trees. Caterpillars feeding on red oaks that were defoliated more than 50 percent grew to be only two-thirds the size of those feeding on trees with intact foliage. Since our experimental caterpillars still had plenty of food, we had to conclude that their growth was reduced by declining leaf quality, not quantity. Apparently, once the trees passed a critical level of defoliation, they staved off utter ruin by pouring phenols into their leaves.

Because the number of eggs a female moth produces is directly related to her size, and because her size is determined entirely by her feeding success as a caterpillar (adults don't feed), we further concluded that tree defense had to affect moth fecundity.

Other researchers, meanwhile, demonstrated that more than a score of trees have "induced defense" responses, including such gypsy moth favorites as aspen, alder, willow, maple, and apple. With this news, a reasonable model of the gypsy moth cycle began to emerge: Defensive responses by trees reduced the caterpillar population; but as soon as outbreaks faded, tree defenses waned. Then female caterpillars eating phenol-free leaves

Enter the Fungal Factor

by Ann E. Hajek

The blackened bodies of dead gypsy moth caterpillars covered the gray oak trunks of a shady Connecticut woodlot. It was mid-June 1989, and I, along with other scientists who were closely watching the buildup of another population cycle, was puzzled. We suspected that the culprit wasn't the common gypsy moth wilt virus, because it spreads only at the height of infestations, after very dense caterpillar populations have been defoliating trees for at least one year.

But caterpillar populations that June were still sparse. Furthermore, the cadavers were solid and mainly oriented head downward, whereas caterpillars killed by the virus are oozy and generally hang from their midbody with head and abdomen dangling.

We dissected these cadavers and, unexpectedly, found multitudes of fungal spores. Although a fungus is known to cause spectacular epizootics among Japanese populations of gypsy moth caterpillars, and efforts have been made by myself and others to release the pathogen in this country, the fungal epizootic in Connecticut was the first reported in North America.

News of the discovery spread fast among the community of entomologists and foresters that have been battling gypsy moth defoliations for decades. Caterpillars from all over the Northeast were sent to our laboratory for dissection, and to our great surprise, biochemical analysis of enzymes and DNA fragments of the fungus isolated from cadavers revealed that the pathogen was the same as that known to cause epizootics in Japanese populations. The fungus *Entomophaga* (Greek for "insect eater") *maimaiga* was found in samples from six other northeastern states as well.

But how did it get here? In the early 1900s, researchers at Harvard University learned of the Japanese fungus and succeeded in bringing a few infected Japanese caterpillars back to the Harvard Botanical Garden. The fungus from these infected larvae was propagated and released around Boston in 1910 and 1911 in the hopes of controlling gypsy moth outbreaks. The experiment failed.

This was the only documented instance of the fungus's being intentionally introduced into North America before 1985. In 1985 and 1986, I was part of a team introducing it into southwestern New York and northwestern Virginia. But by mid-June of 1989, our efforts had not caused die-offs at our release sites.

Perhaps we are now seeing the legacy of the 1910–11 introductions, because to have spread over so large an area, the fungus must have been established for some time. Perhaps some previous die-offs attributed to the virus were actually caused by this fungal pathogen. (To most observers, cadavers of gypsy moth caterpillars killed by the fungus look very similar to those killed by the virus.)

In mid-June 1990, the fungus again caused widespread die-offs, this time in three more states. As in 1989, May was rainy, apparently favoring the fungus. Yet most of the caterpillars became infected in June, which was generally dry. How much moisture is necessary for the fungus to cause epizootics?

Entomophaga, *magnified by electron microscopy, forming spores*
T. Butt

We are left with more questions than answers. Are these fungal die-offs rare events or has the fungus been killing some gypsy moth larvae all along? And what factors trigger its ability to infect the caterpillars?

What we do know is that the organism lives in northeastern forests and woodlots. Given a combination of factors, the fungus may be able to stop gypsy moth caterpillars in their tracks.

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A female gypsy moth, top, lays a mass of buff-colored eggs, which she covers with hairs from her body. The size of the mass, perhaps 500 or more eggs, indicates that a caterpillar outbreak may be imminent. Bottom: Newly hatched larvae are buff colored but turn black within about four hours. If the weather is rainy or cool, the larvae remain on the egg mass; otherwise, they are attracted by the sunlight and move up the tree trunk to begin feeding in the leafy canopy.

Hiroshi Ogawa; Nature Production

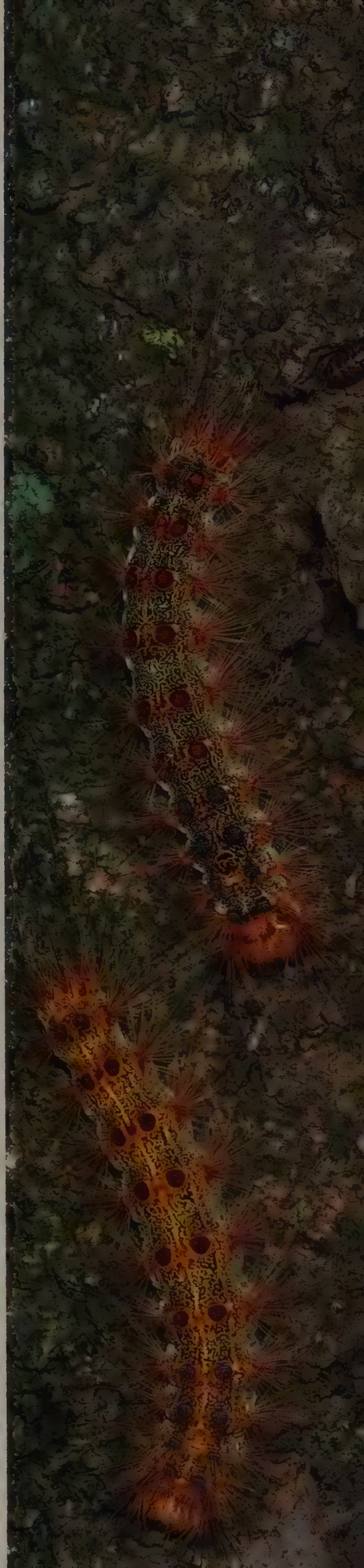
Robert Noonan

could grow bigger and lay more eggs (as many as 1,000 eggs when an outbreak begins, compared with 75 or 100 as the outbreak tapers off and during low-density years). Natural predators and parasites could not keep up with outbreaks. We reasoned that the rise and fall of tree defenses, together with the impact of natural enemies, might explain the ups and downs of the gypsy moth cycle.

But which natural enemies were important and how did tree defenses affect them? The gypsy moth is subject to a variety of bacterial, fungal, viral, and microsporidian diseases that could play a role in its population dynamics (see box). Experienced insect pathologists assured me that gypsy moth nucleopolyhedrosis virus, or wilt disease (so named because dead caterpillars hang limply from trees), was a particularly important killer of the caterpillars in outbreak years. Several studies have suggested that throughout the world, this viral disease causes outbreak populations to crash.

Caterpillars contract wilt disease when they eat a leaf to which the virus, encased in a protein globule, has attached itself. The protein coating around the virus dissolves in a caterpillar's gut, releasing thousands of viruses, or virions, that after about two weeks multiply enough to fill the entire body cavity. When the caterpillar dies (its body collapses and becomes an oozing mass), the virions are released to the outside, encased in a new protein coating synthesized from the caterpillar's tissues and ready to be picked up by another caterpillar.

Such viral epizootics occur only when caterpillar populations are very dense. In outbreak years, as much as 99 percent of a population can be infected. When caterpillars are few and far between, however, few are likely to encounter the pathogen at all, and many viruses die before finding a host. (The virus can, however, stay alive outside a host for at least a year if shielded from ultraviolet light. Sometimes, rain washes the protein cases containing the pathogen from the leaves onto tree trunks where female gypsy moths deposit egg masses over them, protecting the virus from sunlight through the winter. Larvae



Late-instar caterpillars, which can grow to be three inches long, eat voraciously at night and travel down the tree trunk to rest during the day. The larvae secrete white trails of silk that serve as anchors and allow them to find their way back up the trees.
Hiroshi Ogawa; Nature Production

chewing their way out of the egg mass early the following spring become infected and carry the virus onto the leaves. There they die, leaving more viral protein cases for other caterpillars to ingest.)

Because phenols, including tannins, often act by associating with, and altering the activity of, proteins, Penn State researchers Bill Yendol, Bill McCarthy, and Steve Keating and I were curious about the effects of ingesting the virus and leaves together. We undertook a series of studies to determine whether different leaves have differing effects on the virus's ability to kill caterpillars. We found that on tannin-rich oak leaves, the virus was considerably less effective at killing larvae than when it was on aspen leaves, which are lower in phenols. In general, the more concentrated the phenols (which depends on the type of tree, soil quality, water availability) in tree leaves, the less deadly the virus. We even discovered that in the laboratory, we could stop the viral infection altogether by using purified phenolic compounds like those found in oaks. We have yet to identify the actual biochemical mechanisms involved, but we suspect that when phenols are present, the viral protein does not readily dissolve inside the caterpillar's gut, so the deadly virions are not released. Alternatively, phenols may interfere with the virus's ability to recognize and infect gypsy moth cells.

So far, we have determined that highly concentrated phenols in trees reduce the caterpillar population by limiting the size of caterpillars and, consequently, the size of the female's egg cluster. But we also know that these same chemicals help caterpillars survive by disabling the wilt virus. Forest stands of red oaks, with their tannin-rich foliage, may even provide caterpillars with safe havens from disease. In stands dominated by trees such as aspen, however, incipient gypsy moth outbreaks are quickly suppressed by viral epidemics.

Recently we were able to show that larvae become virtually immune to the virus as the trees on which they feed respond to increasing defoliation. Tree defenses raise the threshold of caterpillar vulnerability to disease and also allow populations to grow denser without becoming more susceptible to infection. For these reasons, the benefits of ingesting phenols appear to outweigh the costs. Given the presence of the virus, the trees' defensive tactic apparently has backfired.

As far as the gypsy moth is concerned, the disease-related benefits of eating certain kinds of leaves may have selected for continued feeding on phenol-rich trees despite their effects on egg production. Whether phenol-resistant viruses have evolved remains unknown. I would suspect that if there is a virus resistant to the leaf phenols, it does better and better as an outbreak persists (two to three years), and selection may favor it during this short period. This resistant virus would displace its more vulnerable counterpart, the tree's influence on disease would therefore eventually break down, and the virus population would shift to the resistant type. This would explain how a viral infection could end a caterpillar outbreak even as the leaves were becoming more and more toxic to the virus.

Only during the past ten years have ecologists integrated disease into their studies of insect populations, probably because most of us were not trained in microbiology or pathology. But the influence of pathogens on the lives, populations, and communities of many organisms forces us to expand our perspective. Plant pathologists tell me how difficult it is to study plant viruses when phenols are present. Recent studies have shown that plant phenols are effective agents against polio, herpes simplex, hepatitis, and rabies viruses in humans and in animals.

In nature, this means that disease–host interactions are frequently mediated by diet; in the case of gypsy moths, by tree leaves. We cannot understand these interactions or their outcome without detailed studies of the mechanisms involved and the collaboration of scientists with widely divergent skills. This approach has brought us a little closer to understanding aspects of this three-sided interaction between trees, gypsy moths, and disease, but we have yet to pinpoint precisely what happens. In the meantime, outbreaks this summer may be massive, as war and pestilence in the canopy go on. □

Traveling at a speed of up to 150,000 miles per hour, a comet or an asteroid colliding with the earth would leave a crater more than a hundred miles in diameter. In this artist's rendition of the late Cretaceous impact, a six-mile-wide comet strikes an ocean.
Don Davis

Cretaceous Ground Zero

Sixty-five million years ago, a large asteroid or comet struck the earth with devastating consequences, but where is the crater?

by Alan R. Hildebrand and William V. Boynton

In February 1990, while Bill Boynton, my adviser and collaborator, worked on his projects, I traveled to Haiti's southern peninsula to examine a key piece of evidence in our search for the scar left by a comet or an asteroid that struck the earth at the end of the Cretaceous, 65 million years ago. Leaning into the steep hillside, I scraped away loose dirt and vegetation obscuring the underlying rocks. With help from Dave Kring, a colleague at the University of Arizona, I gradually exposed a fresh surface and began collecting samples from the various sedimentary layers.

Sandwiched in the middle of a thick sequence of light gray marine limestone of the Beloc Formation (named for a nearby Haitian village) is a 1½-foot-thick layer of greenish brown clay. Below this layer are the microscopic fossils of plankton that lived in the seas at the end of the Cretaceous; above it, the fossils date from the earliest Tertiary. The clay bed is like a bookmark inserted between two chapters of the earth's history: one dominated by giant reptiles; the other ruled by mammals. Although some paleontologists argue that the dinosaurs were already in decline shortly before the end of the Cretaceous, none have been found in rocks younger than 65 million years. Mammals had coexisted with the giant reptiles for millions of years, but only in the early Tertiary did they begin to rapidly diversify, filling the void left by the extinction of the dinosaurs. The change in sea life was equally dramatic. In a geologic instant, almost three-quarters of all marine species became extinct at the boundary.

Although I had studied the Cretaceous–Tertiary (K–T) boundary at sites from Alberta to Austria and had previously seen samples from the Haitian boundary collected by Florentine Maurrasse, a geologist at Florida International University, my excitement grew as I examined half a dozen outcrops of the clay layer where the Beloc Formation angled across the hills. The rocks at each exposure had been altered by the severe weathering typical of the tropics and distorted by the folding and faulting that complicates much of the Caribbean's geologic past. One outcrop, however, recorded the final events of the Cretaceous with remarkable clarity. With the same care that a paleontologist gives to preserving a rare dinosaur bone, I wrapped a thirty-pound chunk of the fragile clay in a cement-and-burlap jacket for transport back to the laboratory at the University of Arizona. I had taken many samples, but with a piece of the outcrop, I could show others exactly what the Haitian layer looked like.

At the very top of the boundary layer lies a pencil-thick sheet of gray clay. This layer has been found around the world wherever a complete sequence of the boundary strata is preserved. An outcrop of this clay layer in Italy's Apennines range, near the town of Gubbio, provided the first tangible evidence that a comet or an asteroid might have been responsible for the mass extinction at the end of the Cretaceous. In the late 1970s, after returning from a field trip to the area, Walter Alvarez, a geologist at the University of California at Berkeley, mentioned the strange clay to his father, physicist Luis Alvarez, also at Berkeley.

Luis Alvarez suggested measuring the amount of iridium in the clay. This novel approach might reveal whether the clay had been deposited over a short period or had accumulated gradually. Iridium is an extremely rare element in the earth's outer crust. Early in our planet's evolution, iridium and the other platinum group metals, such as palladium and osmium, migrated downward with metallic iron to form the earth's core, leaving the mantle and crust almost devoid of these elements. What little iridium could be measured in the clay layer would probably have come from meteorites, whose high concentrations of the element reflect its abundance in the material from which the solar system formed. Assuming that the rate at which meteoritic dust settles has not changed since the Cretaceous, the amount of iridium in any layer would provide a rough estimate of how quickly the layer accumulated. The Berkeley scientists were surprised to find that their samples from the boundary near Gubbio contained thirty times more iridium than could be explained by even the most gradual accumulation of the clay. Samples of the layer collected from other parts of the world showed even higher concentrations of this rare element.

After puzzling over these extraordinary results for several weeks, Luis Alvarez and his colleagues reached a startling conclusion: the iridium might have come from a single, very large meteorite striking the earth. They estimated that a comet or an asteroid about five miles in diameter would be required to supply the approximately 200,000 tons of iridium in the

layer. (We suspect that it was most likely a comet because comets contain lower concentrations of iridium than most asteroids and can strike the earth at higher speeds, producing a bigger impact for the same amount of iridium. We will assume the impact was caused by a comet, but an asteroid is still a possibility.) The Berkeley group also guessed that the impact lofted enough debris into the atmosphere to completely block sunlight from the earth, thus bringing photosynthesis to a halt. In the cold and dark, the world's ecosystems collapsed, precipitating widespread extinctions on land and in the seas. In the dozen years since the Alvarez paper was published, other researchers have proposed many more lethal effects of a large impact. Acid rain derived from burning nitrogen in the atmosphere, for instance, may have caused the marine extinctions, but any number of impact-induced changes in the environment may have contributed to the demise of any one species.

The Alvarez hypothesis was not entirely new. As early as 1750, Pierre de Maupertuis, a French scientist, proposed that comets had occasionally struck the earth, causing extinctions by altering the atmosphere and oceans. The iridium anomaly discovered by the Berkeley group, however, established the first real link between a catastrophic impact and a mass extinction and touched off a lively and often heated debate over the significance of the boundary layer. Some researchers maintain that the iridium in the clay resulted from a prolonged period of intense volcanism. Similarly, they argue that the volcanism could have precipitated the mass extinction.

But whether or not the impact is directly responsible for the mass extinction, we believe that the accumulating evidence for a large impact at the end of the Cretaceous is overwhelming. In addition to the iridium (which has been found in the same thin clay at more than 100 sites around the world), the other platinum group elements are present in the same ratios found in meteorites. The ratios of these elements in volcanic dust, however, are different by a factor of 500. Moreover, minerals in the clay layer, such as shocked quartz, show features that can be produced only by the sudden, high pressures created by an impact. The most violent volcanic eruptions have never produced shock features like those found in some boundary layer minerals.

One missing piece of the puzzle, which would eliminate the remaining doubts about the impact origin of the clay layer, is the crater's whereabouts. The comet would have blasted a hole more than 100 miles in diameter in the earth's crust. But where is it? Clues to its location are found in the boundary layer.

From observations of cometary orbits, we know that the speed of the approaching comet was enormous—as much as 150,000 miles per hour. As the comet ripped through the earth's atmosphere in just a few seconds, its surface became white hot. Then, as the comet plowed into the earth, the impact created tremendous pressures and temperatures—as much as one million times atmospheric pressure

On the moon, bright rays of ejecta blasted from the impact that produced the sixty-mile-wide crater Copernicus stand out against the dark lunar surface.
The Hayden Planetarium

Joe LeMonnier

and several thousand degrees. The violence of the collision completely vaporized the comet and ten times its mass of target rock: the material sprayed outward from the expanding crater at fifty times the speed of sound. The blast, which released a thousand times the energy of the world's nuclear arsenals, punched a broad hole some twenty-five miles deep in the crust and mantle. The fireball created by the impact expanded upward, carrying some 400 cubic miles of debris high above the atmosphere. (For comparison, the 1980 eruption of Mount St. Helens ejected less than a third of a cubic mile of ash into the atmosphere.) Much of the finer material drifted in the stratosphere for several months before it eventually settled to the ground, coating the entire globe with a thin layer of iridium-rich dust, the "fireball" layer.

Directly beneath the fireball layer lies the "ejecta" layer. This second, distinct layer is found only at localities in the vicinity of the crater and was deposited by a different process. Some 5,000 cubic miles of melted and crushed rock was ejected outward from the crater, unimpeded by the atmosphere (which was partly blown away by the shock of the impact), and fell back to the ground within a few hours. Given the size of the impact, the ejecta blanket should be recognizable more than 3,000 miles from the crater in every direction. The blanket should be thickest near ground zero and become thin and patchy at greater distances.

In 1985, Jan Smit, a geologist at the Geological Institute of the Free University in the Netherlands, noted the presence of the separate ejecta layer underlying the thinner fireball layer at several North American localities and concluded that the impact probably occurred in this part of the world. Since then, an ejecta layer about three-quarters of an inch thick has been found at many other localities in the United States, Canada, and the nearby oceans. The ejecta layer is missing altogether from boundary sites in Europe, Asia, Africa, the western Pacific, and New Zealand.

One look at the K–T boundary in Haiti and the significance of the site becomes apparent. Directly beneath the thin gray clay of the fireball layer lies a pale greenish brown clay layer, one and a half to four feet thick. Now resting high in the mountains, this clay—the ejecta that settled on the floor of the ancient Caribbean Sea—contains some of the largest grains of shocked quartz yet discovered and in quantities ten times that of other K–T sites. In addition, the layer is packed with rounded grains, called tektites, that are generally similar in size to BB shot, but with some examples as large as one-third of an inch long. As molten rock sprayed outward from the impact and arced across the sky, the droplets congealed into glass with characteristic forms, such as dumbbells, teardrops, and elongated spheres. Generally, the tektites have been altered from the original glass, but at least three groups of researchers have found glass cores in some of the Haitian grains. The discovery of tektites, which can only come from an impact, provides further proof that one occurred at the end of the Cretaceous. The most outstanding characteristic of the Haitian ejecta layer, however, is its thickness; at least twenty-five times that of any other ejecta layer, it indicates that the K–T crater is nearby.

Despite considerable efforts to find it, the crater has eluded geologists for a number of reasons. On our moon, craters more than 4 billion years old have changed little since their formation. Surveys of the other planets and their moons have revealed that impact craters are the dominant landform on almost all the solid bodies in the solar system. Undoubtedly, this was once true of the earth as well, but because of powerful forces of erosion and active geol-

The twin craters of the Clearwater Lakes in northern Quebec are thought to have been formed about 300 million years ago by the simultaneous impact of two asteroids.
U.S. Geological Survey EROS Data Center, Space Shuttle Mission 61-A, Roll 35, Frame 86

ogy, which continuously change the landscape, craters have become temporary features on our planet. In the 65 million years since the end of the Cretaceous, a crater could have been obliterated by erosion, buried beneath miles of sediment, or deformed beyond recognition by mountain-building processes. Another possible reason that the K–T crater has not yet been found is that the comet struck a part of the ocean floor; since the end of the Cretaceous, roughly half of the oceanic crust has been recycled into the mantle, so there is a reasonable chance that the crater has been destroyed.

Nevertheless, about 120 impact craters have been found on the earth, and a few additional ones are discovered each year. Perhaps the most spectacular and easy to recognize on a map is the Manicouagan crater in eastern Quebec north of the Saint Lawrence River. A ring-shaped reservoir more than forty miles across fills the depression that remains from an impact 210 million years ago. The Popigai crater in Siberia is more than sixty miles across and about 40 million years old. The remnant scars of impacts found in Sudbury, Canada, and Vredefort, South Africa, are even larger and more than a billion years old. Such discoveries show that impact cratering is an ongoing process and give us a hint of far more violent collisions in our planet's early history (*see* "Birth of the Moon," *Natural History,* November 1989). None of the known craters, however, are the right age and large enough to be the site of the Cretaceous impact.

Because the fireball layer and the ejecta layer contain large amounts of rock from the site where the comet struck, their composition should give us an idea of where to concentrate the search—in the oceans or on land. After several billion years, various geologic processes have produced significant differences in the chemical compositions of continental crust, oceanic crust, and the mantle; each contains a characteristic amount of each element, depending on whether it has been enriched or depleted since the planet's formation. Even the isotopes of a single element (chemically identical atoms with different atomic weights) can be found in differing amounts in the two types of crust and the mantle.

By the mid-1980s, when we became interested in this problem, several other research groups had already measured the isotopic and chemical composition of the target rocks. Although consistent with an impact in oceanic crust, their results did not show an exclusively oceanic signature. An added complication is that the original material has been almost completely altered at all known K–T sites, raising the possibility that the original chemical composition has changed. We decided to measure the abundance of the rare-earth elements. Because their distributions in the two different kinds of crust are markedly different, they could help us distinguish which type of crust was represented in the K–T boundary layer. Furthermore, our laboratory was already set up to analyze these elements with high accuracy. By 1987, we were able to show that the unusual rare-earth element pattern of the boundary layer could be explained by a mixture of oceanic and continental rock. Although the oceanic signature was dominant, the mix of continental and oceanic crust suggested an impact on the edge of an ocean basin.

Given the geochemical evidence for an ocean impact, we began combing scientific journals for mention of unusual K–T boundary deposits that the waves from such an impact might have left behind. An impact in the deep ocean would have created a set of waves three miles high. Reaching above the clouds, the waves would travel outward, like ripples on a pond, at several hundred miles an hour.

The first evidence of the huge waves produced by the impact began to appear in the mid-1980s, when Smit first proposed such an origin for a formation that outcrops along the banks of the Brazos River, not far from Waco, Texas. Further investigation of the outcrop revealed an extraordinary layer: a chaotic mix of rock fragments (some almost three feet in diameter) lies on an irregular surface eroded into a late Cretaceous formation. From the size of the boulders and their jumbled appearance, we concluded that an enormous wave was indeed responsible for the deposit—one that is unique in the local outcrops, which record 7 million years of geologic history.

Although the Brazos River site is now more than 300 miles from the coast, 65 million years ago it was part of the continental shelf, submerged under several hundred feet of water. The scenario we envision is that a few hours after the impact, the waves swept landward across the shelf. And like ocean waves cresting when they reach the shallows near shore, the

impact waves rose to heights of several hundred feet as they moved onto the shallow shelf. Although much of their destructive energy had dissipated as they spread out across the oceans, the waves were still powerful enough to tear up the bottom sediments and transport the debris miles across the shelf.

Similar deposits have been found along the southern margin of North America where a shallow sea once reached far inland. In 1984, Ernest Glick and Charles Stone, two government geologists, described coarse deposits in Arkansas, up to sixty-five feet thick and containing blocks as large as sixteen feet, and suggested an impact-wave origin for them. These shallow-water deposits may represent material that was dumped by the impact waves as they swept onto land and back out again.

In terms of size, the most spectacular wave deposit yet found stretches from the western tip of Cuba to the center of the island. In 1986, Andrzej Pszczolkowski, a Polish geologist, described a single, massive bed at the K–T boundary. He attributed its peculiar nature to massive slides caused by a large earthquake, but he noted the possibility that the earthquake itself might have been triggered by an impact. Ranging from 20 to 1,500 feet in thickness, the deposit contains blocks of rock more than 5 feet in diameter lying in the chaotic heap. Although the boulders were deposited in a deep trough north of the Cuban volcanic arc, many of them are composed of shallow-water sediments. We believe that large waves from the impact swept across the lowlands of the ancient Cuban islands, tearing up boulder-sized pieces of the terrain and dumping them into the trough. Millions of years later, the wave deposits and other accumulated sediments were pushed up onto the northern coast of Cuba as the Caribbean plate moved northward. Additional wave deposits at the K–T boundary have been found at other sites in Mexico and the Caribbean, as well as one in northern South America. Similar deposits are not known from the K–T boundary anywhere else in the world. This scenario suggests that the comet landed somewhere between North and South America.

Closer to the site of the impact, the waves were so large that they ripped up ocean bottom sediments and redeposited them over hundreds of miles. On the chance that the effects of the waves might be recorded, we searched the reports of the Deep Sea Drilling Program, which has directly sampled sediments and crust from ocean depths around the globe. Concentrating on the sites drilled between North and South America, in April 1988 we found two that fit the prediction. Both were in the Colombian Basin in the southern Caribbean, and because the waves could only disturb the bottom sediments in the vicinity of the impact, we felt certain that the crater was nearby.

Our search now focused on the Colombian Basin, and new pieces of the puzzle began to fall rapidly into place. Back in 1987, our search of the literature had turned up the 1½-foot-thick K–T boundary layer in Haiti. It was the closest out-

In this painting, which depicts a scenario different from the illustration on page 46, an asteroid strikes the edge of a continent. The cratered surface of the asteroid suggests the prevalence of collisions in the solar system.
Don Davis

crop of the clay layer to the Colombian Basin, and if we were correct in thinking that the impact had occurred nearby, it might be a thick ejecta layer. In June 1989, I visited Maurrasse, who had discovered the Haitian boundary deposits but thought they were volcanic in origin. Immediately after looking at his samples, I knew that they represented impact ejecta because of the tektites.

We had also begun searching geophysical surveys of the Caribbean sea floor for evidence of a crater. Seismic reflection data can reveal the major features of the geology hidden beneath the ocean bottom. Waves generated by small explosions bounce off the various geologic formations and are detected back at the surface. Computers then translate the signals into a crude picture of the geology along the route traversed by the survey ship. Because much of the Caribbean has been crisscrossed and mapped by surveys for oil exploration and scientific purposes, large areas of the sea floor that reveal no signs of a large crater could be ruled out.

Soon after we became aware of the spectacular ejecta deposits in Haiti, we found our first candidate for the crater. The roughly circular structure on the floor of the Colombian Basin, fifty miles from the South American coast, had been reported by geophysicists Chris Bowland and Eric Rosencrantz. Revealed by seismic surveys, the structure is buried beneath a mile and a half of sediments that were dumped into the basin, primarily by Colombia's Magdalena River. With additional data obtained from Columbia University's Lamont-Doherty Geological Observatory, we could trace the circular edge of roughly half of the structure. At 190 miles in diameter, it is twice the size of any known crater on earth.

A circular shape is a good sign of an impact crater, but the finding is far from conclusive. Several large circular features on our planet's surface (such as one along the eastern edge of Hudson Bay) have been suggested as possible K–T boundary craters, but further investigation has ruled out an impact origin, and they are not in the right place to match the evidence. In the case of the Colombian Basin structure, however, the few details revealed by the seismic profiles support its impact origin. But because only half the structure has been revealed so far, additional seismic data are needed to determine whether or not the structure is indeed circular. If so, drilling in the basin by the Deep Sea Drilling Program may be warranted to verify its origin and age.

In 1990 we, together with geophysicist Glen Penfield and other co-workers, identified a second candidate for the crater. It lies on the northern coast of Mexico's Yucatán Peninsula, north of the town of Mérida. The structure, which we named Chicxulub for the small village at its center, is buried by a half mile of sediments. Decades earlier, unusual circular magnetic and gravitational anomalies were recognized in the area, but aside from a suggestion that it might be a crater (in an abstract by Penfield and Antonio Camargo), nothing was ever published about it. The structure has escaped proper investigation because most of the samples from drilling operations in the area were destroyed in a warehouse fire, and the geophysical data were all proprietary, having been acquired for petroleum exploration.

Geophysical surveys and oil well information show a circular basin more than 100 miles in diameter, filled with thick deposits that may be melt rocks and impact breccias, the shattered rocks that line crater floors. We, together with Dave Kring, have found shocked quartz and other evidence confirming the structure's impact origin. The age of the crater's formation is not precisely known, but the fossil information available places the crater within 5 million years of the K–T boundary. The crater will have to be redrilled to get samples to determine its exact age.

Although this crater lies on continental crust, we would never have found it without using impact wave deposits as our primary guide. At the time of the impact, the Yucatán Peninsula was below sea level, a continental shelf. An impact in the shallow sea could have created large waves, while at the same time providing the continental material (shocked quartz and feldspar) to the boundary layers. The tektite glass in the Haitian ejecta layer is the most reliable evidence yet of the type of crust involved in the K–T impact. The unaltered glass has an unusual chemical composition that is intermediate between oceanic and continental crust—similar to that of the rocks at the Chicxulub crater. The isotopic composition of the tektites is also intermediate between the two types of crust. This may be consistent with the Chicxulub site and would explain most of the previously acquired isotope data.

An impact at the Chicxulub site could have produced a dramatic climatic change by a mechanism first suggested by John D. O'Keefe and Tom A. Ahrens, of CalTech. They have suggested that because limestone stores carbon dioxide in the form of carbonate minerals, an impact into a thick formation of the rock would have released huge amounts of carbon dioxide into the atmosphere—enough to produce severe greenhouse conditions for tens of thousands of years. Because the Yucatán Peninsula is covered by a two-mile-thick slab of limestone, the Chicxulub impact would represent a worst-case scenario for O'Keefe and Ahrens's theory. After the immediate lethal effects of the impact passed, a long-term climatic change may have occurred, extending the period of extinctions and killing those species that survived the initial effects.

The evidence suggests that the Chicxulub crater could be the sole K–T boundary crater; its size, location, and target rock composition are consistent with most of the properties of the boundary layers. But whether the Chicxulub crater or the Colombian Basin structure proves to be the K–T crater, the evidence remains that an enormous meteorite struck the Caribbean area at the end of the Cretaceous. Because the search has narrowed to this region of the earth, the existence of the K–T crater may soon be confirmed, resolving the decade-long debate over the Alvarez hypothesis. Whether the impact is solely responsible for the extinctions is a separate question that will only yield to further scrutiny of the fossil record, but knowing the location and size of the impact will give us a clearer picture of the cataclysmic event. □

Boojum in flower, Sonora, Mexico
David Burckhalter

A Tree Grows in Baja

The boojum knows how to bide its time

by Robert R. Humphrey

What is a boojum? According to an undoubted authority, Lewis Carroll, "the Snark *was* a Boojum, you see." This isn't very enlightening, since Carroll failed to describe a Snark. But we do know that one so unfortunate as to see a boojum would "softly and suddenly vanish away," a fate that befell the intrepid Baker in Carroll's tale *The Hunting of the Snark.*

The boojum, long rooted only in literature, took on a botanical identity one day in 1922. As recounted in *The Forgotten Peninsula,* by the essayist Joseph Wood Krutch,

> An expedition led by Mr. Godfrey Sykes of the Desert Botanical Laboratory in Tucson went to study some strange plants found near Puerto Libertad [on the coast of the Sea of Cortés]. . . . The party reached the area late one afternoon and Mr. Sykes focused his telescope on the hills where the plants had been seen. . . . He gazed intently for a few moments and then exclaimed, "Ho, ho, a boojum, definitely a boojum."

Thus a desert tree became, at least in the vernacular, the namesake of the mythical boojum. Known scientifically as *Idria columnaris,* the boojum has been variously described as unique (what life form isn't?), fantastic, grotesque, bizarre, slender and like a candle, beautiful, and ugly. It may grow to a height of more than eighty feet and reach an age of 700 or more years in an area where the average annual rainfall is only five inches. In that part of Mexico where the boojum is native, it has been known as the *cirio* since the days of the first Spanish missionaries, who noted a resemblance between the tall trees that bore a cluster of yellow flowers and the slender wax tapers, or *cirios,* used in their church services.

The first-known description was by the historian Francisco Clavijero in 1789 (*The History of [Lower] California*):

> Much more curious is another tree . . . which is found frequently from 29° to 31°. It had not been seen by the missionaries before the year 1751, because they had not gone into the interior of that country. Nor do I believe that it has been known until now by naturalists. It is so large that it grows perpendicularly to a height of seventy feet. Its trunk, thick in proportion, is not woody but soft and succulent like the branches of the *pitajo* and the *cardón.* Its branches are certain little twigs about a foot and a half long, covered with small leaves and protected by a thorn on the end; they do not extend upward or horizontally, as the branches of other trees do, but they hang downward like a beard, from the top to the bottom of the trunk, and the top produces some little bunches of flowers, where no fruit is ever seen.

Krutch's description captures some of the tree's more striking variations:

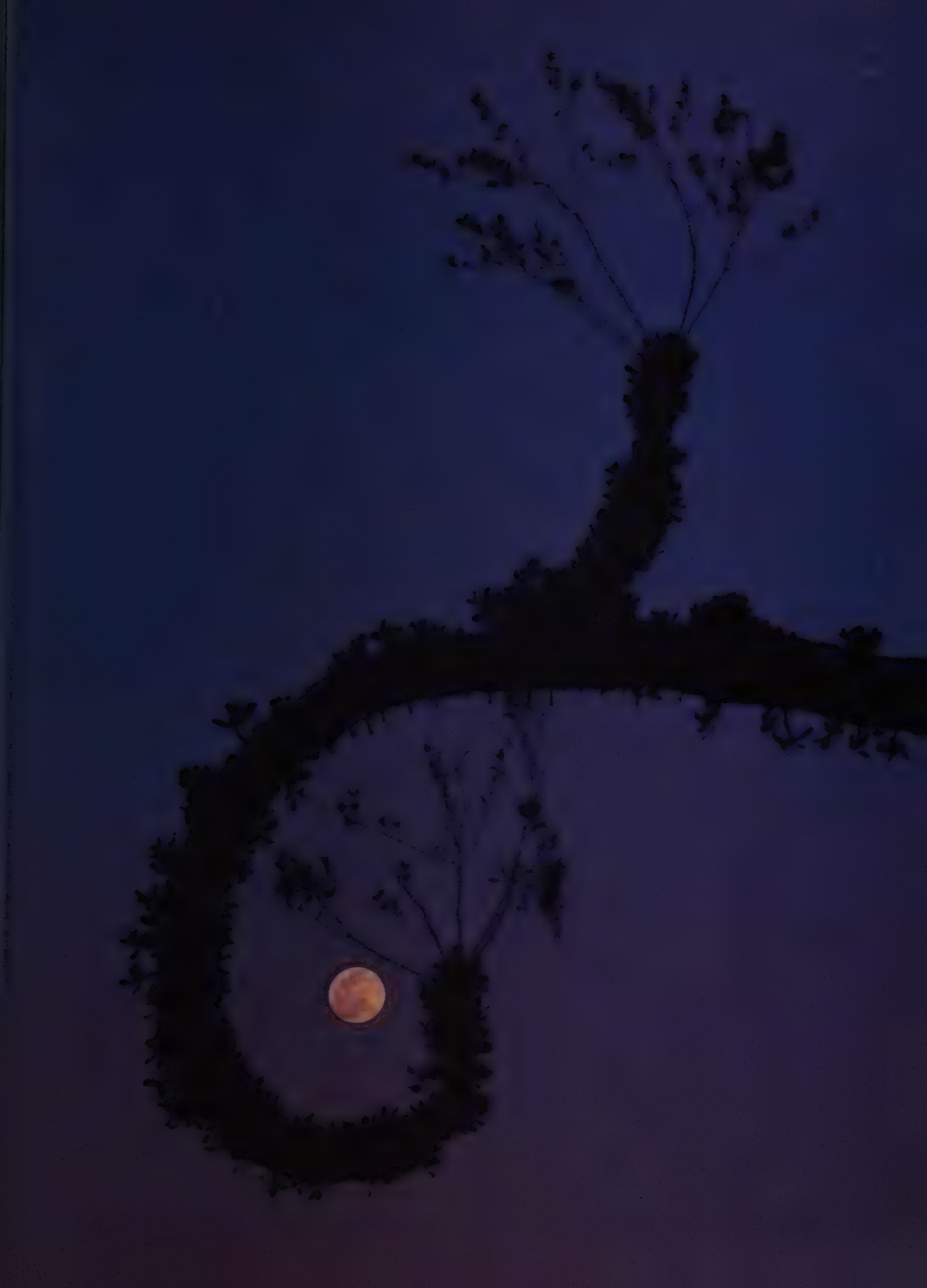
> What, then, is this astonishing tree like? The right answer is "like nothing else on earth," though the commonest description is "like an upside-down carrot improbably provided with slender, spiny and usually leafless branches which seem to be stuck helter-skelter into the tapering carroty body." . . . They often branch in an absent-minded manner toward the upper end, and sometimes, as though embarrassed by their inordinate length, curve downward until the tip touches the earth and thus becomes what is perhaps the only tree which makes a twenty-foot-high arch like a gateway into a wizard's garden.

Many years ago, while at the University of Minnesota, I studied the anatomy of the boojum tree and its smaller relative the ocotillo. Some pickled boojum material from the same stand of trees spotted by Godfrey Sykes was mine for study. During the course of my research, I came to know the plants in their native desert habitat, and much later I was able to devote a full five years to an exploration of their ecology. Through familiarity, they have lost their strangeness, but they have always retained their fascination. I have the feeling, when walking in a boojum forest, that this primitive-looking tree is still trying to figure out how to grow and just what configuration to take.

The boojum is found in Baja California only in a restricted portion of the peninsula, the most northerly individuals occurring near El Rosario, some 200 miles below the international boundary at Tijuana. From there its range extends to the southeast for some 275 miles to Las Tres Vírgenes, a quiescent volcanic mountain near San Ignacio. No fossil or other evidence exists to indicate the range of the boojum throughout its long history.

Baja California seems to have been the boojum's geologically recent, primary home, while the comparatively small Sonoran colony probably developed when the light, wind-disseminated seeds, which ripen during the late-summer hurricane season, were blown 75 to 100 miles across the Gulf of California (Sea of Cortés). Although boojums thrive best in both the deep soil of the interior valleys and the shallower soil of the rocky hills of the central peninsular interior, occasional individuals and some small colonies of the trees are also found close to the foggy, humid, cool Pacific coast. Across the peninsula toward the gulf, where humidity is low and summer temperatures are almost unbearably hot, boojums, unless deliberately transplanted by humans, grow no closer than twelve miles to the coast. In the interior of Baja, where they are most at home, boojums commonly grow in association with other plants endemic to that part of the Sonoran Desert, most notably the elephant tree, datilillo (a treelike yucca), and giant cardon cactus.

Boojums are by far the tallest plants growing in the Sonoran Desert. But how



Tom Danielsen

Up to 200 years old, a boojum outstrips a giant cardon cactus in Baja California, right. Boojums naturally grow upward, but a loss of turgor during a prolonged drought may cause drooping and the formation of such abnormalities as an archway, below.

David Burckhalter

can the slender spire of a tree with a basal diameter of twenty to twenty-five inches have survived the countless storms, often with hurricane-force winds, that must have buffeted it for six, seven, or even eight centuries? The tallest-known boojum towers some eighty-six feet. The wind sings through its tiny branches, and the trunk sways gently as it yields to the desert winds.

A combination of features gives the boojum its ability to survive against great odds. Had Clavijero been entirely correct when he wrote that the trunk of the boojum was "not woody," none of the seventy- or eighty-foot-tall individuals that amaze us today would exist. The trees must store large amounts of water in soft, succulent tissues during the rainy season, yet they accomplish this without sacrificing trunk strength. This strength is provided in great part by the xylem, or conductive tissue, a cylinder of wood near the outside of the trunk that surrounds and protects the reservoir of thin-walled, water-storing cells within. This woody cylinder is not only strong but also flexible; the tree trunk sways but seldom breaks. The short, slender boojum branches usually bear no leaves that might offer resistance to the wind during the hurricane season. In Baja California, most of these storms come in September and October, when the boojums are leafless after a long, hot, dry summer. So the wind whistles through a plant that barely resists its passage and seems even to welcome its caresses.

The woody cylinder offers little protection over the years from gnawing desert animals or woodpeckers. The boojum, however, has developed another feature that not only adds to its strength but also provides a peripheral plate of armor. So close to the thin outermost epidermis as almost to be a part of it lies a several millimeter thick cylinder of essentially impregnable, contiguous groups of stone cells. Beneath this layer lie the otherwise vulnerable cambium and phloem, in addition to the all-important reservoir of pith cells with their stored water.

While the small and widely dispersed stone cells found in pears, for example, may be a bit of a nuisance to a human (they are the gritty inclusions in the fruit's juicy flesh), the boojum's contiguous stone cells provide the tree with an effective barrier to the teeth of hungry and thirsty beasts. The boojum probably couldn't survive without them. Perhaps the stone cells appeared in a prototype of the boojum and, as the species evolved and survived under increasingly arid conditions, the cells increased in number and utility.

Survival of any species is possible only through survival of individuals. And they survive only because of their ability to endure the vicissitudes encountered

A young boojum, about three inches across, may have eked out its living in a granite crevice for about twenty years.
David Burckhalter

throughout their life spans. This brings us back to the boojum, a species that has somehow persisted and endured for eons, and whose ancestors, according to paleobotanist Daniel Axelrod, probably date from the Permo–Triassic epoch some 200 million years ago. The plant's survival, if not the plant itself, is an apparent paradox. In my study of the boojum's life cycle from germination to final establishment, I found what seemed to be an evolutionary weak link, a real *faux pas*. Although each mature plant produces no-one-knows-how-many seeds, these are not clothed in a hard coat that would protect them against ever-hungry birds, rodents, and insects. Sheer numbers, however, compensate for this apparent vulnerability, so although perhaps not the strongest link in the chain, it would not appear to be the weakest.

The light, windblown seeds are produced—come rain or shine—in seemingly infinite numbers and at a time of year when they would apparently have the best chance of germinating. The winter rains, if they come, usually start in November or December, soon after the seeds ripen in late October or early November. This, therefore, would seem to be one of the stronger links in the boojum chain.

During repeated germination tests, I found that most mature boojum seeds are viable. Given adequate moisture and warmth, they germinate readily and quickly, desirable traits in a desert plant whose seeds have no hard coat or other apparent built-in deterrent against seed eaters. But I was greatly surprised when these tests showed a seeming flaw in the tree's finely tuned adaptations. Although almost all the seeds germinated in about a week, the seedlings died if allowed to wilt even once. Young plants of most species will recover after wilting, but not young boojums. In a hot, desert area where five

David Muench; David Muench Photography

With tiny side branches, a boojum clothed in leaves, right, exhibits an unusual growth pattern. Leaves sprout in early winter but turn yellow and fall off in spring, preventing water loss through evaporation during the summer. More typically, below, hundreds of spindly branches sprout from a triad of stems growing from a single root stalk.

Larry Minden; Minden Pictures

or six inches of rain a year is the norm, how could this seeming liability be part of the boojum's bag of survival tricks?

Only when the seedling has managed to survive for some six weeks can it avoid death by desiccation. By that time, the stem, about as thick as a lead pencil, has begun to store water. The soil may now dry out to a point where the young boojums lose all of their leaves, but unless rain fails to fall for months on end, the trees are not likely to perish.

The boojum's home range is characterized by two so-called wet seasons, summer and winter. Summer rains, however, are infrequent and brief, and summer temperatures high, guaranteeing rapid drying. The soil cannot retain enough moisture to permit both germination and six weeks' continuous growth. Lower winter temperatures and winter rains, which may fall intermittently for several days, are much more likely to provide the continuous soil moisture the boojum seedlings need to survive.

Even so, maintaining moist soil to a depth of several inches for at least six weeks is a tall order in that part of the Sonoran Desert. Although I found a number of pencil-thick boojums, during only one spring in my five-year study did I come across any that could truly be classified as seedlings. And by the summer of that year all of these had vanished. I finally concluded that only once every fifteen or twenty years would sufficient rain fall and the soil remain moist enough to permit actual establishment of a new generation of boojums.

One's first reaction to this kind of occasional and accidental provision for the survival of a species might be that it just couldn't have worked down through the centuries. Yet, obviously, it has, and for some 200 million years. Why? Perhaps because the boojum is never in a hurry. Once every fifteen or twenty years, a few seedlings survive the first critical weeks, but even for them growth is a slow process. Twenty or thirty years may come and go before their main stems have grown three or four inches tall. Even after that, years may go by when the rains are too light to sustain any new growth. At long last, through sheer persistence and after the passage of half a century or so, the boojum may be ten or twelve feet tall and mature enough to flower and produce seeds. With six or seven hundred years of life ahead of it, the boojum can afford to bide its time.

The rains will come or they won't. The boojum will grow a little or simply wait until the next year or the next. With or without rain, it will always blossom; bees will pollinate its flowers and produce the seeds that may—but probably won't—give rise to a new generation of boojums. Hurricanes, earthquakes, seasons, and years will come and go; the boojum stands and waits for *mañana*. □

Partners in Carnivory

North America's coyotes and badgers have an ancient bond

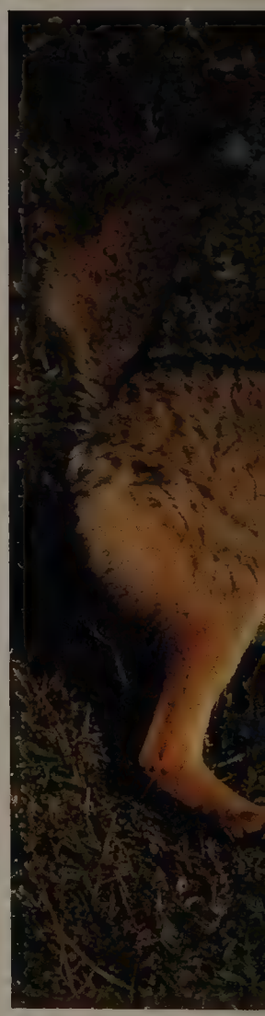
Text by Kathryn A. Minta and Steven C. Minta

A red-tailed hawk dives overhead, warning us to keep a proper distance from its nest. Chattering ground squirrels seem to be everywhere. Appreciative of all the side attractions, we again direct our attention downslope to a badger's radiotelemetry signal and a hunting coyote. Thick vegetation makes the badger harder to track than the coyote, but with the aid of telemetry signals we have been watching this pair hunt ground squirrels for more than an hour. We refocus our binoculars as the pair enter a dense squirrel colony. In pursuit of its quarry, the burrowing badger throws a plume of dirt into the air, while the alert coyote maneuvers through the adjacent sagebrush. Suddenly, the coyote becomes a blur of motion, scrambling and pouncing on a squirrel bolting from its exit hole several yards away from the digging badger, which quickly vanishes below ground, where we assume it is cornering and capturing a squirrel. (Badgers customarily eat their prey in the privacy of an underground burrow.) The satisfied coyote awaits the badger's return, but after twenty minutes it loses

A badger interrupts its digging to keep an eye on its hunting partner.

Left: Ready to pounce on a fleeing ground squirrel, the coyote stays alert.

Right: A crouching coyote signals amicable intent; the badger nonetheless hisses to keep the coyote at a distance.



patience and trots off. Below ground, the badger is no doubt cooling off and resting after its meal. The close association and mutual tolerance displayed by these two carnivores have abruptly ended, and we can only anticipate our next chance at observing such a remarkable partnership.

During our three-year study of North American badgers in northwestern Wyoming's Jackson Hole, we often came upon such two-species teams. A coyote (occasionally two or three) would work with one badger to capture a hapless Uinta ground squirrel at its burrow. Our study area was in the National Elk Refuge, a sagebrush-grassland community of flats, hollows, and aspen stands, where coyote and badger populations are very dense as a result of land management practices and restrictions on human visitors. Ground squirrels are deep in hibernation eight months of the year, but they are fairly active above ground in late spring to early summer, when new grasses and forbs are abundant. At this time, too, their population swells, and they become the chief prey for the two larger animals.

Although rarely witnessed nowadays, the remarkable relationship between coyote and badger must be a longstanding one, because it is well recorded in the language, art, and folklore of western Native Americans. White Mountain Apache referred to the two species as cousins that travel together, and the Navajo portray them as hunting partners that call each other cousin. A pre-Columbian pot found in Casas Grandes, in northern Mexico, pictures the head of a coyote on one side and a badger on the other. Some Mexican Indians still refer to the badger as *talcoyote,* Aztec for "coyote of the earth." Early explorers and pioneers of the European invasion also wrote of this curious partnership, but few field biologists have reported the phenomenon, perhaps because badgers keep a very low profile in their current range and coyotes are wary of humans.

On the Elk Refuge, however, coyotes are easier to spot; and when we saw a coyote conspicuously loitering, we often found a hunting badger nearby. The relationship is an odd partnership: the badger is a

The coyote escapes with the ground squirrel that the badger flushed out.

digging specialist; the coyote an opportunist. The omnivorous coyote is constantly on the lookout for potential food. Any disturbance in the environment—such as a digging badger—may attract its attention and provide an opportunity for a meal. Frequently, sheer curiosity seems to draw the coyote to the site of the badger activity. For its part, the badger has extremely acute senses of smell and hearing that enable it to detect prey through soil. Its compact and powerful musculature and skeleton are designed for breaking ground and burrowing. As soon as it senses a subterranean ground squirrel, the badger digs down to the burrow, enters it, and corners its intended victim. Often, however, burrows are interconnected, with a number of escape routes. The coyote is good at locating such exits and is as adept at pouncing, aboveground captures as the badger is at subterranean ones. A ground squirrel facing a two-species team is therefore at an extreme disadvantage, and we have found that coyotes working with badgers catch more squirrels than they would alone. Badgers pursue and eat most of their prey underground, so we have only indirect evidence that they are taking more prey because of the association. Their tolerance of coyotes, however, suggests that badgers, too, benefit from the relationship.

Although badgers sometimes become aggressive if a coyote comes too close, there are moments when we understand how some people may be tempted to anthropomorphize a bit about a friendship between the species. We have seen hunting partners travel together over a period of weeks. And we have come upon coyotes briefly resting near or touching a badger, sometimes pawing at it. Occasionally, a badger reciprocated. We have even seen playful coyotes try to coax badgers into play. In general, however, badgers are impervious to the exuberant attentions of these members of the sociable dog family.

Although we saw badgers and coyotes together year round, most of their partnerships are forged during the high season, when ground squirrels are active and scrambling above ground. Only the digging badger can capture hibernating ground squirrels, so when winter comes to the valley, some fair-weather friendships may cool, and hungry coyotes might start looking at badgers, especially the young of the year, as prey.

Animal ecologists Kathryn A. Minta and Steven C. Minta live in Whitefish, Montana. Kathryn works in the field of environmental education; Steven is a consultant to the Northern Rockies Conservation Cooperative and to Biota Research and Consulting.

At the American Museum

Man and Nature Lecture

William Schopf, a professor of earth and space sciences at the University of California, Los Angeles, and director of the Center for the Study of Evolution and the Origin of Life, will present the 1991 Mack Lipkin Man and Nature Lecture at the American Museum of Natural History on Monday, June 10, and Tuesday, June 11. Schopf's topic is fossils from Precambrian times and the influence of these early organisms on the basic organization of the present-day biological world. Both lectures will begin at 7:00 P.M. in the Main Auditorium. Advance admission for the two-evening series is $20 ($10 for Museum members) and may be ordered from the Membership Office, American Museum of Natural History, Central Park West at 79th Street, New York, NY 10024-5192. Call (212) 769-5606 for further information.

Identification Day

On Saturday, June 1, from 1:00 to 4:30 P.M. in the Hall of Ocean Life, staff scientists will be on hand to identify, analyze, and classify artifacts and natural objects (no gemstones, please) for the public. Experts from New York City's Department of Environmental Protection will test water samples and answer questions about chlorine, phosphates, pH, turbidity, and water quality. (Bacteria and lead testing are not included.) Call (212) 769-5305 for further details.

Adventures in the Field

Sidney Horenstein, coordinator of the Museum's environmental programs, will lead a series of cruises in the New York area. On Tuesday, June 4, from 6:00 to 9:00 P.M., an evening geology cruise around Manhattan will survey the origins of the Palisades and other landscape features. Tickets are $25 ($22 for members). On a three-hour boat tour on Tuesday, June 11, from 6:00 to 9:00 P.M., passengers will learn how the bays and waterways of metropolitan New York were formed and observe the surprisingly abundant bird life. Tickets are $25 ($22 for members). The Hudson estuary and Upper Bay, Gowanus Bay, the Narrows, Gravesend Bay, and Rockaway Inlet will be featured in a day trip on Saturday, June 22, from 11:00 A.M. until 4:00 P.M. Tickets are $35 ($32 for members). Participants in the three cruises should bring a box meal. All field trips are for adults only. Call (212) 769-5305 for information.

The Asmat: A Portrait of a People

This month, a series of lectures will explore many aspects of the culture of the Asmat, New Guinean hunter-gatherers. Carving, ceremonial drumming, dancing, storytelling, art, and social and environmental issues will also be addressed. Among the speakers will be Carlton Gajdusek, who received a Nobel Prize in medicine for isolating the "kuru" virus, cause of a devastating brain disease that afflicted New Guinean tribesmen. Gajdusek will talk about cannibalism and disease in New Guinea on Monday, June 24, at 7:00 P.M. in the Kaufmann Theater. For particular events, dates, and times, please call (212) 769-5315.

A company of nearly sixty performers from Shimane, an area on the southwestern coast of Honshu, will depict the natural beauty and myths of the region through music and dance. The presentation takes place in the Main Auditorium at 7:00 P.M. on Tuesday, June 4. Admission is free.

As part of the Museum's Asian/Pacific American celebration, aspects of Philippine dance and literature will be presented on Saturday and Sunday, June 1 and 2. On the following weekend, June 8 and 9, the music, arts, crafts, and life styles of Hawaii will be featured. Both programs, highlighted by short films, will be held in the Leonhardt People Center from 1:00 to 4:30 P.M. Admission is free. Call (212) 769-5315 for additional information.

Free Programs

Latin American music and dance, from the traditional to the modern, will be presented by the group Los Pampas on Sunday, June 2, at 2:00 and 4:00 P.M. in the Kaufmann Theater.

The Brazilian martial art *capoeira,* developed by African slaves from Angola, was disguised as a dance in order to be practiced openly. Other traditional dances from Brazil will be performed by Jelon Vieira's DanceBrazil on Wednesday, June 5, at 7:30 P.M. in the Main Auditorium. Call (212) 769-5315 for further details.

Each year, Earthwatch, a nonprofit, Boston-based organization, sponsors 140 field research studies in forty-three coun-

A DanceBrazil performer
Cylla Von Tiedemann

Treehoppers, Monteverde, Costa Rica

Dan L. Perlman

tries. Volunteers, as well as scientists, can participate. A slide-illustrated program about Earthwatch expeditions will be presented on Wednesday, June 12, at 7:00 P.M. in the Kaufmann Theater. Call (212) 769-5305 for information.

Photography Exhibits

The Museum's Department of Entomology has compiled a selection of photographs of insects and arachnids from the forests of Costa Rica and Panama. This exhibit is on display in the Akeley Corridor through June 2.

Native North American fishes are remarkably diverse, but because many species live in the riffles of streams or in small bodies of water, people are unaware of their numbers or their beauty. Of the 713 native freshwater fishes in North America, 364 species are now considered endangered, threatened, or of special concern. A broad selection of photographs of these fishes will be on display from June 14 through September 22 in the Akeley Corridor.

UFOs: Visitors from the Stars

Few phenomena have sparked the imagination as much as UFOs. In a program premièring Thursday, June 27, the Hayden Planetarium looks at the UFO question and tells about actual efforts by scientists to contact intelligent alien beings. For information about this and other sky shows, call (212) 769-5920.

These events take place at the American Museum of Natural History, located on Central Park West at 79th Street in New York City. The Kaufmann Theater and the Leonhardt People Center are located in the Charles A. Dana Education Wing. The Museum has a pay-what-you-wish admission policy. For more information about the Museum, call (212) 769-5100.

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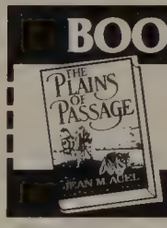

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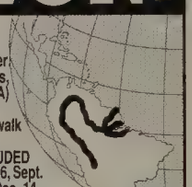

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Kendall Warm Springs, Wyoming

by Robert H. Mohlenbrock

While it ends by rushing turbulently into the Colorado River, the Green River rises 730 miles away among the small alpine lakes, springs, glaciers, and streams high in Wyoming's Wind River Range. After a northwestward descent, the river turns abruptly and begins its southward flow through a broad valley. Within a few miles, it is fed by the clear waters of Kendall Warm Springs, which cascade over a ten-foot-high ledge of white travertine, a rock built from calcium deposits. Named for an early logger in the region, the springs are part of the Bridger-Teton National Forest.

The springs get both their calcium and their warmth from a low limestone ridge some 1,000 feet east of where the springs enter the river. As surface water in the ridge circulates down through subterranean cracks and fissures, it penetrates deeply enough to be warmed by the rock, emerging from the hillside at 85° F. The springs consist of three major and several smaller flows that drop into two main pools at the foot of the ridge. The water then continues in a stream, often fanning out into a series of rills until it pours over the waterfall into the Green River.

A strong odor of sulfur emanates from the springs. Fisheries biologist Niles Allen Binns has analyzed the water and found it also abundant in other dissolved minerals, particularly calcium, magnesium, sodium, and potassium. At the source along the limestone ridge, the warm spring water is very high in carbon dioxide but low in dissolved oxygen. As it percolates downstream, the water gives off some of the carbon dioxide and gains more oxygen from the air.

While this part of Wyoming has severe winters with recorded temperatures as low as −54°, the water in the Kendall Warm Springs stream never drops below 78°. Following a heavy winter storm, mounds of sparkling snow border the green aquatic vegetation in the stream, while the water continues to flow. Biologist Galen Boyer has noted that the warm water entering the Green River keeps it free of ice for several miles downriver. Judging from the mink, bobcat, and coyote tracks that are often found on the streamside mud, the springs and the stream appear to be a winter oasis for wildlife.

Kendall Warm Springs and its stream lie in an open landscape. On the limestone ridge, only occasional aspen and rounded, shrubby sagebrush form a canopy above sparse grasses and a few flowering plants. Boggy patches of vegetation and occasional willows grow along the stream, punctuated by yellow monkey flower, silvery cinquefoil, and daisy fleabane. Several plants grow submerged in the water, including large mats of sago pondweed, naiad, and stonewort. Sago pondweed and naiad are flowering plants that form small, obscure flowers and minute seeds, while stoneworts are algae and reproduce without flowers, sometimes forming egg and sperm cells and sometimes forming asexual spores.

Stoneworts lack the complex cellular structure of leaves, stems, and roots found in flowering plants but may form extensive colonies several feet across. An easy way to distinguish stoneworts from similar-appearing pondweeds and naiads is by their feel: stoneworts are stiff and rough, while the others are soft and flaccid. This is because stoneworts (as their name implies) become heavily calcified. At Kendall Warm Springs, calcium from the spring water precipitates in a crust of tiny calcium carbonate crystals over the body of stoneworts. As the plants die and fall to the bottom of the stream, their limy residue accumulates, eventually forming layers of travertine.

Fisheries biologist Binns has also examined the animal life in and near the warm water and recorded an assortment of

Kendall Warm Springs

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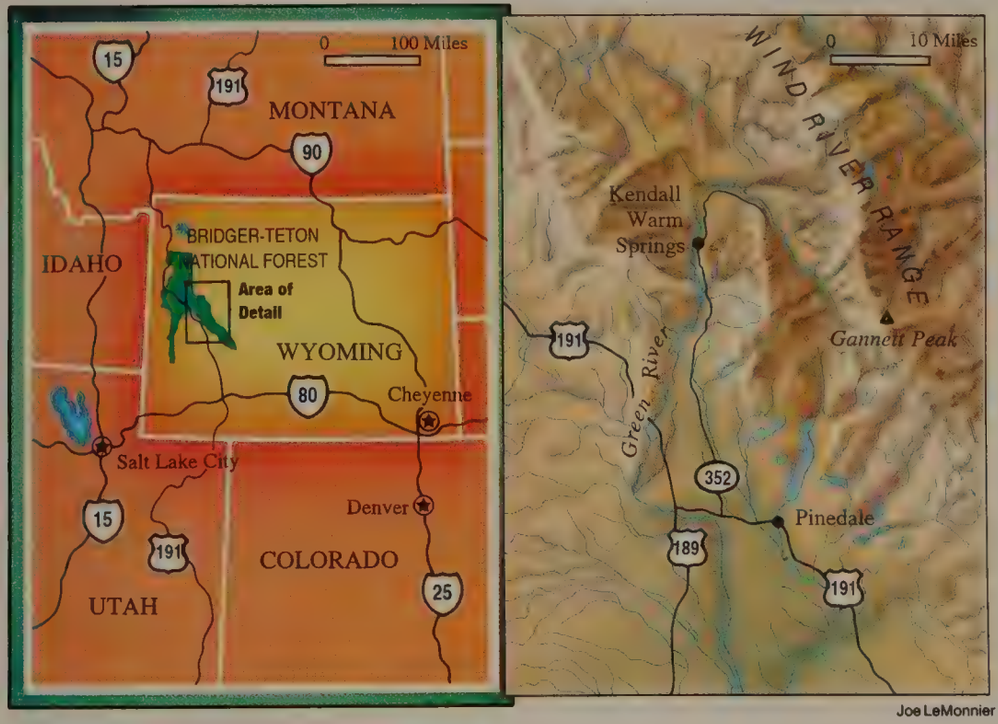


Joe LeMonnier

The Green River
Jeff Gnass

snails, aquatic beetles, buffalo gnats, dragonflies, damselflies, caddis flies, crane flies, and soldier flies. While all these organisms are apparently common and widespread, the soldier flies have attracted special interest. Related to, but smaller than, horseflies, soldier flies are usually brightly colored and shiny and possess short, spinelike projections over part of their body. Fly authority Harold Oldroyd finds these features unusual in an organism that does little but rest, mate, and lay eggs.

The soldier fly's coloration may relate to the way the insects swarm before mating, glistening as they flit through the sunlight. When at rest, the soldier fly crosses its wings in a scissorlike fashion, covering the bright markings so that potential predators will not be alerted to its presence. Its spinelike projections may also offer protection. The larvae of the soldier fly lie nestled in decaying, moist vegetation along the stream. Their roughened skin is also due to the deposition of calcium carbonate. Oldroyd postulates that the crust may protect the delicate larvae from desiccation during dry spells.

Only one kind of fish swims in these springs, the Kendall Warm Springs dace, a 1½-inch-long relative of the minnow. Recorded no other place in the world, it has been considered an endangered species under federal law since 1973. It is related to the speckled dace that lives in the Green River, but the latter species has never been found in the warm spring waters. (Nor do the Kendall Warm Springs dace survive if they enter the Green River, where they encounter not only different water temperature and chemistry but also hungry trout that linger in the vicinity.) Some biologists have questioned the distinctiveness of the dace in the springs, but the special conditions in the spring waters and their probable isolation from the Green River for several thousand years (due to the waterfall at the end of the stream) have given the fish the opportunity to develop its own characteristics.

Discovered by forest ranger Harmon Shannon in 1934, the Kendall Warm Springs dace was described by fisheries biologist Eugene R. Kuhn and his colleague C. L. Hubbs. They called it an odd little fish unlike those seen from any other body of water. The females, which outnumber the males four to one, are a mottled dull green, while the males, particularly during the breeding season, are bright purple. The fish live along the entire length of the stream except in the uppermost pools, where the level of carbon dioxide is too high for them to survive. The main channel of the stream contains primarily adult fish, while young of all ages remain under the protective cover of aquatic vegetation in small, shallow pools.

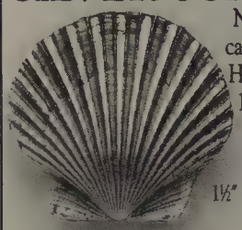
Although the number of Kendall Warm Springs dace appears stable today, the survival of the fish was threatened until it received adequate protection under the Endangered Species Act. Grazing livestock used to wander across and into the stream, disturbing the fragile ecosystem, until the U. S. Forest Service fenced off the area. For many years, the warm water stream was also used for bathing and washing clothes. Since soaps and detergents were potentially harmful to the organisms inhabiting the water, the Forest Service banned all such activities in 1975. And until it was forbidden, fishermen used to take the dace as bait. As a result of these measures, the Kendall Warm Springs dace is now more secure.

"This Land" highlights the biological phenomena of the 156 U. S. national forests. Robert H. Mohlenbrock is Visiting Distinguished Professor of Plant Biology at Southern Illinois University at Carbondale.

The waters of Kendall Warm Springs, above, cascade into the Green River.
N. Allen Binns; Wyoming Game and Fish Department

Ten miles east of the springs, the Green River Lakes, right, reflect Square Top Mountain.
Jeff Gnass

SILVER SCALLOP PIN



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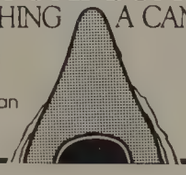

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The Sun's Ups and Downs

by Thomas D. Nicholson

Summer begins on June 21, the longest day of the year in the Northern Hemisphere. The earliest sunrise, however, is on June 14 and the latest sunset is on June 27. The reason for this is the uneven rate at which the sun's position in the sky changes from day to day.

The tilt of the earth's axis, 23.5 degrees away from being perpendicular to the earth's orbit, creates our annual cycle of seasons. As the earth orbits the sun, the Northern Hemisphere tilts toward or away from the sun, so that we experience summer and winter, respectively.

This also causes the sun's daily path across the sky to vary from its low at the beginning of winter to its high at the start of summer. The higher the sun as it crosses the sky during the day, the more time it spends above the horizon. Because of the tilt and the earth's slightly elliptical orbit, however, the rate of daily change in the sun's altitude varies, being greatest during the equinoxes and least at the solstices. These irregularities make the sun a less-than-perfect timepiece, and corrections must always be applied to the time a sundial shows.

The time on our wrists is ultimately based on an imaginary "mean" sun that averages the daily changes in the sun's position. Because of the two major irregularities mentioned, during some part of the year the real sun rises, reaches noon, and sets earlier than the mean sun; at other times the true sun lags behind the mean sun. This is why the dates of earliest sunrise and latest sunset do not coincide with that of the summer solstice, or longest day. Similarly, the dates of earliest sunset and latest sunrise are different from that of the winter solstice, or shortest day.

Events in the calendar below are given in local time unless otherwise indicated.

June 1: Venus, Jupiter, and Mars, the three bright planets, steal the show this month. They hover in the west for several hours until after twilight. The brightest is Venus, which will be the lowest planet in the first half of the month. Jupiter is second brightest and highest but becomes the lowest later in June. Mars, between Venus and Jupiter, is the dimmest of the three, but it is brighter than any star in Cancer, where the planets are gathering. Tonight the bright stars Pollux and Castor are directly right of brilliant Venus.

June 2: The waning gibbous moon passes Saturn in Capricornus. Saturn and the moon rise about midnight and stay up past dawn.

June 5: Last-quarter moon is at 11:30 A.M., EDT, shortly before it moves into Pisces. The moon appears in the Southern Fish (a faint pentagonal pattern) when it rises after midnight.

June 6–8: Each morning, the crescent moon appears below the Square of Pegasus, easily visible to the moon's left in the predawn hours.

June 9–10: The two stars forming a triangle with the moon at daybreak on the 9th are Aries' Hamal and Sheratan. Look for the thinner crescent moon again on the 10th, with the Pleiades cluster below it.

June 12: New moon is at 8:06 A.M., and perigee at 8:00 P.M., EDT. Perigee spring tides tonight and tomorrow are higher than normal.

June 13: Venus is at greatest elongation (distance) to the east (left) of the sun, growing in apparent size and shrinking in phase as it moves closer to the earth on the way to inferior conjunction with the sun (passing between the earth and the sun). Binoculars reveal its present "half moon" shape. Venus is now within five degrees of Jupiter and Mars. Watch nightly from now until the 20th to see this exceptional planetary gathering (joined by the moon on the 15th) change swiftly.

June 14–15: Mars and Jupiter are less than two-thirds of a degree apart both evenings; just over one lunar diameter separates them. Jupiter greatly outshines Mars, and Venus, to their right, outshines them both. On the 15th we will have a spectacular view of the planetary gathering, with the crescent moon to the left.

June 16: The planets are to the right of the moon now, forming a compact trian-

gle. During the next week, Venus will get closer to Mars as both pull away from Jupiter. Leo's Regulus is the bright star above the moon.

June 17: The triangle is tighter tonight. Venus passes north of Jupiter about 7:00 P.M., EDT. The two will be closest in our sky when they set tonight, about two lunar diameters apart.

June 18: The planetary triangle is getting wider and is about to break up.

June 19: First-quarter moon is at 12:19 A.M., EDT.

June 20: The waxing gibbous moon passes under Virgo's bright star Spica.

June 21: Summer begins in the Northern Hemisphere at 5:19 P.M., EDT, when the sun arrives at the summer solstice.

June 23: Venus passes Mars at 8:00 A.M., when the two planets are less than a lunar diameter apart. They are close on both nights in our sky but switch places, left to right. Dazzling Venus greatly outshines Mars, however, being more than 200 times brighter.

June 24: Scorpius' Antares is the reddish star near the gibbous moon.

June 26: Look below the rising moon (which is full at 10:58 P.M., EDT) to see the stars of Sagittarius' "teapot." Less than a third of the moon slips into the earth's shadow during a penumbral lunar eclipse at full moon. The moon darkens only slightly and imperceptibly.

June 27: The moon reaches apogee, its farthest point in orbit from the earth.

June 28–29: Still a morning "star," Saturn is only a month from its opposition with the sun, when it makes the transition to an evening object. The waning gibbous moon helps locate Saturn on the 28th and 29th, as it moves from the right to the left of the planet.

Editor's Note: The Sky Map in the April issue shows the evening stars and constellations for this month and gives the dates and times for use.

Thomas D. Nicholson is director emeritus of the American Museum.

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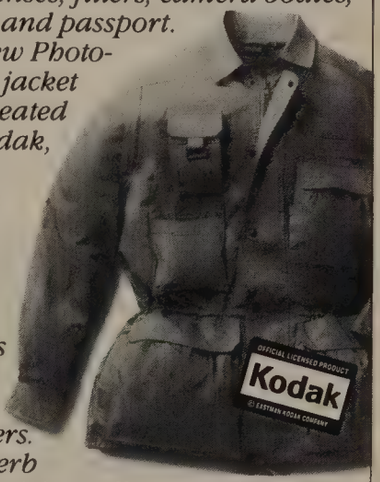

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Eating like a Noble Savage

Even premodern people had convenience food

by Raymond Sokolov

In our technologically advanced state of culture, we first worlders are inclined to mock food products that owe something to industrial science. We are also prone to romanticize simple foods—peasant foods, ethnic foods—foods that smack of premodern purity and closeness to the soil. This yen for the primitive parallels similar impulses well known since the romantic era, in which the highly civilized, self-consciously refined thinkers of the West glorified the lives of people they took to be their opposites. They themselves were corrupted by the decadence of advanced civilization; "savages" were noble.

The appeal of this attitude remains strong for many people today, especially those discontented with their inherited societies. In this country, these neoromantics (hereinafter referred to as NRs) have typically flagellated themselves for the destruction of the indigenous Indian cultures by the advancing wave of white settlement. They tend to see only good in the pre-Columbian lives of the groups they insist on lumping together illogically as Native Americans (this euphemism replaces the imperialist misnomer Indian with a term excluding almost all of us born here since 1492). And the NRs also see only evil in the Western culture brought to these shores.

The coming quincentenary of Columbus's first landfall has already spurred the NRs into action. They are busy dancing their tribal dance, so to speak, hoping to bring down rain on the worldwide parade of events that will celebrate one of human history's most important events next year. In the vanguard of these naysayers is the writer Kirkpatrick Sale, whose book *The Conquest of Paradise: Christopher Columbus and the Columbian Legacy* (Knopf, 1990) does its best to blacken the name of Columbus. Sale's most remarkable stance, however, is not a revisionist slur on the legend of 1492, but a radical enthusiasm for the agriculture practiced on this continent before the arrival of horses, advanced plows, European horticultural science, and the ensuing plague of machines, pesticides, monocropping, and other evils of modern agriculture.

On a less theoretical scale, nice people all around us echo the NR disdain for modern food production when they turn their noses up at what they find for sale in supermarkets. I do this myself, most disdainfully in those aisles that feature packaged, prepared foods—overpriced, pumped full of additives, and tasting like the assembly-line products they are. I am willing to concede that for many people the perceived (and often real) convenience of these foods justifies their cost. And since I am not an expert in the relevant sciences, I'm not ready to join the NRs in condemning all prepared foods as the work of the Evil One. But I do feel on strong ground in the area of taste. And I confidently assert that a great many packaged convenience foods fall short of homemade versions of the same dish.

Some, however, are fine and dandy. Some entirely industrial, mass-produced foods taste very good, and they are the exact modern equivalent of some of the world's most ancient and basic food products. I'm thinking of packaged cold breakfast cereals.

Leaving aside various distracting imponderables, such as the effect of monocropped grains and modern methods of fertilization and irrigation on the environment, I want to discuss breakfast cereals in terms of their preparation after the grain harvest is in, so as to compare them with primitive treatments of grain handed down from prehistory as staples of life.

Take cornflakes. Aren't they the epitome of late-industrial food processing—cornmeal stabilized in a precooked, flattened form, dehydrated for long keeping and ready to eat when moistened? But this is precisely what the Hopis did with hand labor long before Columbus. Today, well-brought-up Hopi girls still toast thin sheets of blue cornmeal dough on stone griddles, then roll them up into cylinders to make traditional *piki*. This process may be more picturesque than what goes on in a cereal factory, and the Hopi product may be more beautiful than cornflakes, but the products are basically the same. I find it impossible not to think of them as closely related convenience foods, sensibly exploiting a staple grain.

The world's cuisines preserve dozens of these prepared grain convenience foods. Italian pastas are the best known. Think also of noodles and grits, hardtack, flat breads, the crusts of old-fashioned pies meant for long storage.

Even these basic traditional convenience foods are a step removed from the most primitive conditions. They require milled flour, which is within the reach of preindustrial, tribal societies, but why compromise? The world offers us some delicious and truly preindustrial, non-European grain foods. Probably the most antique is the cracked-wheat product from the Middle East most commonly referred to here by its Turkish name, bulgur.

According to Michael Abdalla's exhaustive account in the proceedings of the 1989 Oxford Food Symposium, the oldest reference to bulgur is on an Assyrian cuneiform tablet of the ninth century B.C., in a discussion of a feast at the court of Ashurnasirpal II. Abdalla believes that the biblical word *arisah,* usually translated as "dough," refers to bulgur.

Even without accepting these references as definitive, it seems clear that bulgur is a traditional form of grain storage in Assyrian villages in what is now Iraq, and that the bulgur tradition goes back far enough, to a time and way of life sufficiently remote from our own world, to satisfy the most dyed-in-the-wool NR. Abdalla's description of how Assyrian villagers process bulgur even now (or at least before their lives were disrupted by the Mother of Battles) is a Rousseauean idyll in Mesopotamian garb.

"Each family prepares 100–200 kg. of recently harvested wheat for this purpose. First the grain is carefully cleaned: it is sieved manually, sorted on large round trays (every odd grain is removed), rinsed in water several times and dried in the sun. . . . In addition to family members, neigh-

bors also take part in these activities. The activities last a few weeks and are done in leisure time, usually in the afternoons of long summer days."

Next the grain is boiled until it is softened to the point of edibility, called *danoke* or *shleeqa*. The *shleeqa* is then spread thinly on rooftops or other outdoor surfaces and dried for one to three days. "The grain darkens and contracts and looks like wrinkled peas."

The second stage of bulgur preparation is shelling. The dried grains are sprinkled with water to make them flexible. Then they are struck with wooden hammers in a stone hole called a *gurno*, in effect a large mortar. "During the work, men often want to show off in front of their wives and strike the grain with all their might. The hosts' daughters prepare meals for their hard-working parents and at leisure time encourage their fathers. This stage of bulgur preparation is very colorful and truly folkloristic. It is often accompanied by folk songs sung by the children."

One such song was recorded in Syria in 1972:

Himma u haye, himma u ha,
Come girls, come ha . . .
The girls have run and have come!
They gathered around bulgur
in silence.
They rolled up their sleeves
and stood ready.
They looked more beautiful to
the eyes of the boys.
Himmu u haye, strike ha.

After the grain is pounded, it is sun dried again, to facilitate shelling and to enhance its nutty taste. Eventually, the grain is winnowed: cupfuls are poured on the ground and the wind blows away the bran. Finally, the grain is cracked in a quern, a sort of primitive mill consisting of a stationary stone and a movable stone. The cracked grain is sieved so as to separate it into three grades of fineness.

Bulgur keeps well and can be boiled much faster (in about ten minutes) than rice. It is versatile, goes with a large variety of foods (meats, vegetables, legumes), and in Middle Eastern countries, it certainly qualifies as a staple. Indeed, its use is so various and widespread that a complete enumeration of bulgur dishes would be tedious, not to say impossible.

In our day, bulgur has traveled westward and can be found on shelves in American supermarkets. Although still an exotic food, it is nonetheless familiar to most of us in the summer salad called tabbouleh. Habitués of Near Eastern restaurants will have encountered it as a component of the lamb mixture, raw or baked, called kibbe, which is the national dish of Lebanon and Syria.

Oddly, the rise of bulgur in international estimation has coincided with a drop in its stature at home in the Middle East. According to Abdalla, rice has greater prestige because it is imported, and it more and more replaces bulgur as the starch in meat stuffings for vegetables.

This is exactly the kind of situation that NRs in our culture view with alarm. Fortunately, the Middle East does not lack for NRs of its own. One imagines, not without a certain malice, Levantine culinary thought police browbeating cooks to put the bulgur back in their stuffed tomatoes and sheep intestines, to stop eating whatever the local equivalent of Twinkies is and go back to cakes made of fine bulgur and groats of raw wheat. Especially, one hopes, there is great pressure for hand pounding of kibbe and for the studious consumption of that historic remnant of Turkic dining on wind-swept steppes: *tarhana*. This is bulgur mixed with yogurt and left to ferment for several days. The bulgur disintegrates to a pulp. Molded into little balls and dried in the sun, *tarhana* keeps at home for a year.

Every time I eat Grape-Nuts, I think of *tarhana* wistfully, but without wishing I were a Turkish nomad.

Raymond Sokolov is a writer whose special interests are the history and preparation of food.

Raw Kibbe

(Adapted from *Lebanese Mountain Cookery*, by Mary Laird Hamady, Godine, 1987)

About 13 ounces lean lamb
1 cup fine bulgur
½ cup ground onions plus juice
¼ teaspoon ground cinnamon
⅛ teaspoon allspice
1 teaspoon or more salt
¼ teaspoon freshly ground pepper
Olive oil
Finely chopped parsley or chopped scallion or a quartered white onion

1. Be sure to remove all fat and gristle from lamb. Grind twice through fine blade of meat grinder. (In Lebanon the lamb is pounded in a mortar until pasty; the soaked bulgur is worked well by hand to soften it and then mixed with the meat; the two are then well pounded to make a thick paste.) Measure; you should have 1½ cups.
2. Wash bulgur well in a sieve and squeeze out water. Rub well with hands to make it soft. Mix with lamb and onion. Put mixture through fine blade of grinder twice.
3. Add seasonings and work well into meat with hands until mixture is very pasty.
4. Traditionally, a design is pressed into the meat using a fork or dull knife. Form the kibbe into a mound in a shallow dish and draw grooves across the mound in a star shape, passing through the center point with each stroke. Make a slight indentation in the center of the mound and trickle olive oil over the kibbe. Decorate with parsley, scallion, or segments of the quartered onion separated into single layers. Or form the kibbe into balls and score them.

Yield: 3½ cups kibbe; 16 to 21 kibbe balls; 6 to 7 servings

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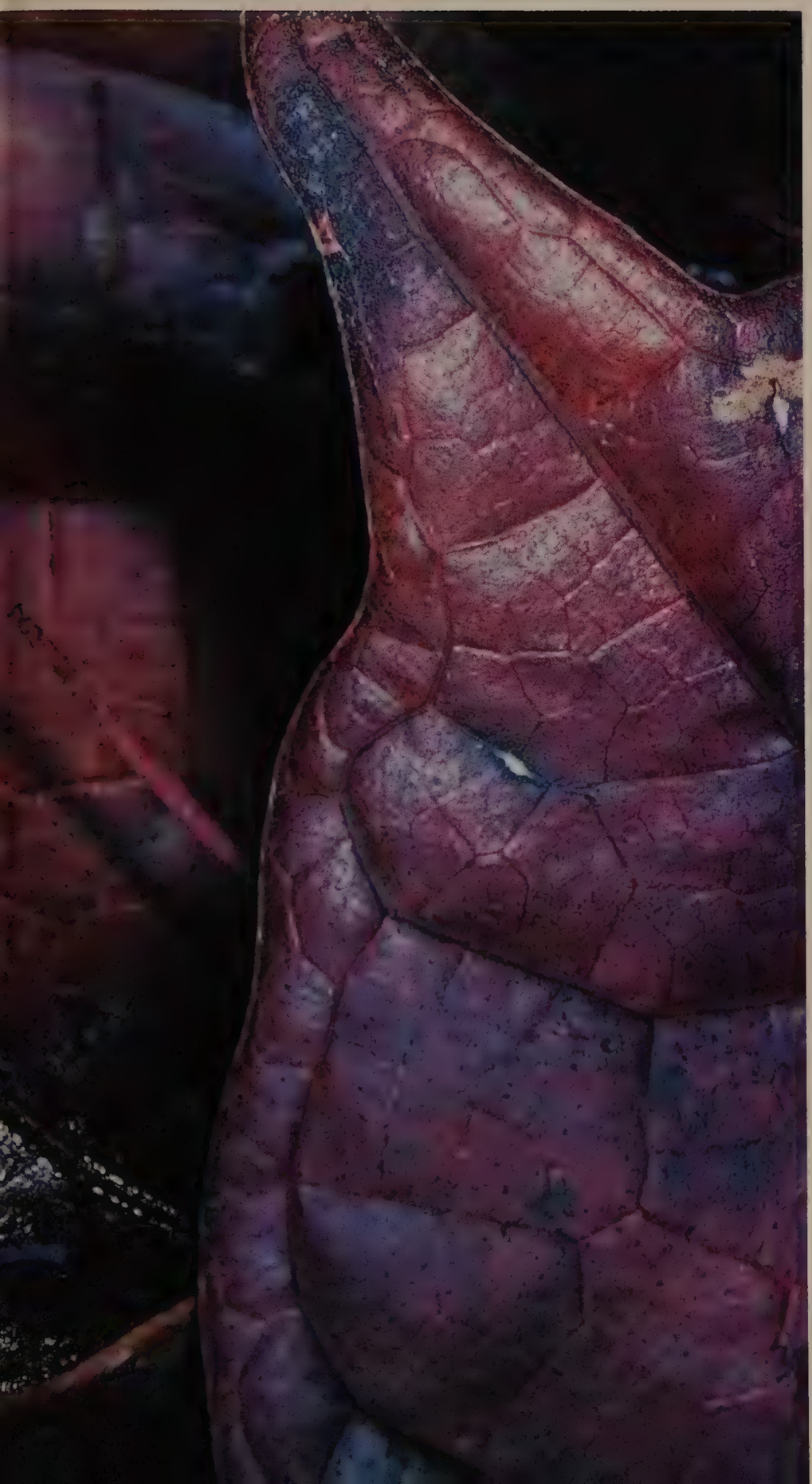

It may be just a leaf to you, but to male strawberry poison-dart frogs in the Costa Rican rain forest, it's part of a breeding ground worth fighting over. Males compete fiercely to control both a territory and a female, sometimes even destroying her previous brood so that they can father a new one.

So named because extracts from their South American relatives are used by Indians to tip their blowgun darts, poison-dart frogs are a classic example of the evolutionary advantages of conspicuous coloration. One brush with the sickening poison, coupled with the reinforcing sight of the frog's bold colors, teaches would-be predators a memorable lesson.

While some poison-dart frogs live up in the trees, this small strawberry-colored species frequents the forest floor. After the female lays her eggs on dried leaves (accompanied by a male to fertilize them), the male repeatedly visits the eggs, keeping them wet with fluids from his body until they hatch. After about two weeks, tadpoles emerge; the female must then carry them on her back, one or two at a time, to a nearby little pool of water, where they mature into adults.

A naturalist of the last century, Thomas Belt, wrote of a Nicaraguan species: "The little frog hops about in the daytime, dressed in a bright livery of red and blue. He cannot be mistaken for any other and his flaming vest and blue stockings show that he does not court concealment. . . . I was convinced he was uneatable so soon as I made his acquaintance and saw the happy sense of security with which he hopped about."—*R. M.*

Photograph by
Michael Fogden

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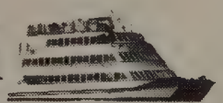

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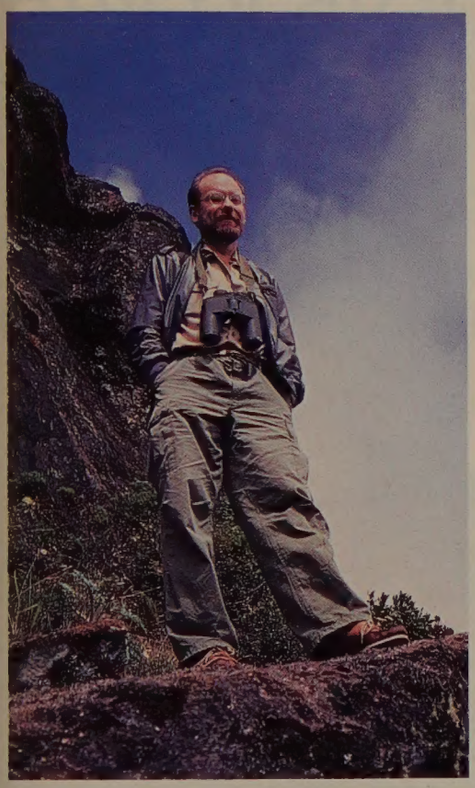
AUTHORS

Ever since he was a graduate student at Columbia University in the 1950s, **Paul Tolstoy** (page 6) has sought to account for the striking similarity between traditional bark-paper making practices in Mesoamerica and Indonesia. The puzzle, first put to him by the late Gordon F. Ekholm, curator of Mexican antiquities at the American Museum, has involved him in a worldwide ethnographic and archeological survey of the tools, procedures, uses, and customs surrounding the manufacture of bark cloth and paper. A professor of anthropology at the University of Montreal, Tolstoy has directed archeological field projects in Ecuador and highland Mexico. For further reading, he recommends *The Aztec and Maya Papermakers,* by Victor von Hagen (New York: Hacker Art Books, 1977); *Traditional Papermaking and Paper Cult Figures of Mexico,* by Alan R. Sandstrom and Pamela Effrein Sandstrom (Norman: University of Oklahoma Press, 1986); "Barkcloth Production in Central Sulawesi," by Lorraine V. Aragon (*Expedition,* vol. 32, no. 1, 1990); and "Trans-Pacific Contacts: What, Where and When?" by Paul Tolstoy (*Quarterly Review of Archaeology,* September–December 1986).

For as long as she can remember, **Sarah A. Sloane** (page 32) has been interested in the private lives of animals: "My first subject was my cat. I was seven, and I followed him around all day just to see what he did with his time." More recently, as an official student of animal behavior, she has assisted in field studies of baboons in Kenya and jays in Mexico, as well as conducting her own work on loggerhead shrikes in Florida. Sloane, who expects to receive her doctorate this month from the University of Michigan, says she originally intended to study large ungulates, but "bird projects kept falling in my lap." She is currently investigating the social behavior and ecology of cooperatively breeding bushtits in the Chiricahua Mountains of southeastern Arizona. A good account of the habits of shrikes can be found in Tom J. Cade's "Ecological and Behavioral Aspects of Predation by the Northern Shrike" (*Living Bird,* vol. 6, 1967); for more on birds' use of inanimate objects in displays, readers may consult Gerald Borgia's "Sexual Selection in Bowerbirds" (*Scientific American,* June 1986).



Many of **Jack C. Schultz**'s experiments with plants, insects, and pathogens take place on his 120-acre farm in central Pennsylvania (page 40). "I can walk out my back door," says Schultz, "and see oaks festooned with bags of caterpillars." Schultz is an associate professor of entomology, ecology, and plant physiology at Penn State's Pesticide Research Laboratory, and in addition to "caterpillar watching" on the farm, he researches plant–herbivore interactions in Costa Rica's tropical rain forest. He hopes to expand his studies of plant–insect–microbe systems to the desert, where fifteen years ago he first began working in the field of ecology. For additional reading, Schultz recommends *Insect Outbreaks,* edited by Pedro Barbosa and Jack C. Schultz (New York: Academic Press, 1989); *The Gypsy Moth, Porthetria Dispar,* by Edward H. Forbush and Charles H. Fernald, edited by Frank Egerton (Salem, NH: Ayer Company Publishers, 1978); and *The Gypsy Moth: Research Toward Integrated Pest Management,* USDA Forest Service Technical Bulletin no. 1584, 1981.

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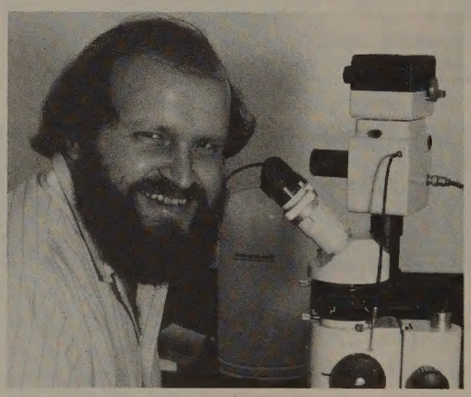
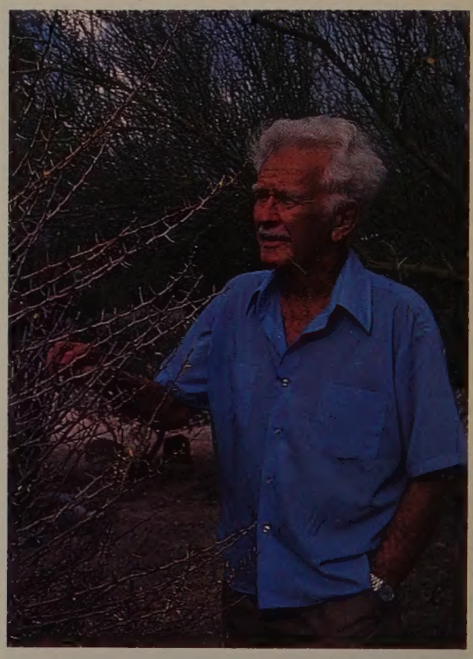
Alan R. Hildebrand and **William V. Boynton** (page 46), of the University of Arizona, have been on the trail of the Cretaceous–Tertiary (K–T) crater since 1984. Hildebrand, shown here examining a section of the boundary layer in Austria, is a native of New Brunswick. He was an exploration geologist in northwestern Canada for six years before moving to Arizona to pursue a Ph.D. in planetary science. His research on the K–T boundary layer has taken him to more than fifty sites around the world. Upon completion of his doctorate Hildebrand will join the Geological Survey of Canada, where he plans to continue his research on the K–T impact and others, many of which left well-preserved craters in northern Canada. Boynton is a professor of planetary sciences, specializing in the chemistry of meteorites. After reading a paper Hildebrand had written on the chemistry of the K–T boundary, Boynton became interested in the problem of the crater's location. Laboratory instruments that Boynton developed for meteorite research allowed them to analyze the composition of the layer with great precision. Boynton has also developed an instrument for the Mars Observer Mission to be launched next year. For additional reading, the authors suggest an article by Walter Alvarez and Frank Asaro, "An Extraterrestrial Impact" (*Scientific American,* October 1990).



"As one walks through the rain forest," says **Michael Fogden** (page 76), "one often comes across pairs of pugnacious male poison-dart frogs engaged in boundary disputes. Sometimes they go at it for an hour or more." Yorkshire-born, Fogden earned a doctorate in ornithology from Oxford University's Edward Grey Institute and for years worked with his wife, Patricia (with whom he is pictured here), on projects as far afield as Uganda (warbler migration) and Mexico's Sonoran Desert (competition between cattle and wildlife). For the last dozen years, the Fogdens have worked in Costa Rica as free-lance writers and wildlife photographers, concentrating on natural history subjects. The photograph for this month's "Natural Moment" was taken with a Nikon F3 and a 105mm lens.



Robert R. Humphrey (page 54) first made the acquaintance of the boojum tree as a doctoral student at the University of Minnesota in the early 1930s. Decades later, he renewed and expanded his knowledge of this desert oddity: "When I had the time and opportunity to explore some of the details of the trees' ecology, from 1967 to 1972, this became an all-absorbing way of life for me and my wife, Roberta." Humphrey's enthusiasm for the boojum extends to its habitat, the strange "Alice-in-Wonderland" splendors of Baja's Sonoran Desert. A professor emeritus in the School of Renewable Resources at the University of Arizona at Tucson, where he taught courses in range ecology, Humphrey continues to study the flora of the Southwest. His current projects include an investigation of the growth rates of the boojum and a study of vegetation changes in the Sonoran Desert. He also continues to explore Baja's "outback" as a scientist and as a back-country hiker and camper. Humphrey is the author of *The Boojum and Its Home* (Tucson: University of Arizona Press, 1974). To readers interested in desert plants he recommends Norman C. Roberts's *Baja California Plant Field Guide* (La Jolla: Natural History Publishing Co., 1989).

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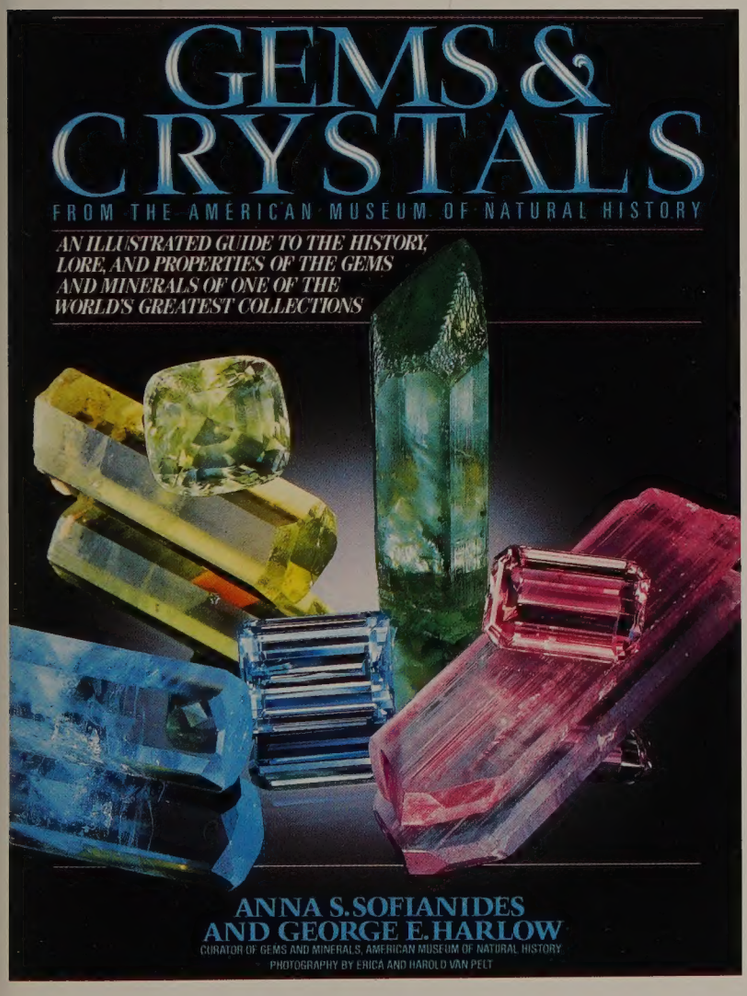
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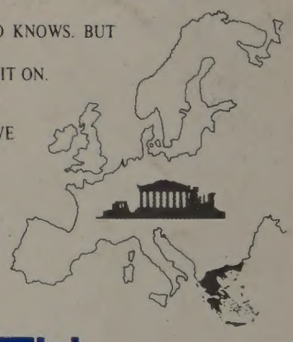

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